ECOLOGICAL INTEGRITY

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Indicators of ecological integrity suggest generally neutral to good conditions in the California Current; however, changes in the loss of some predator fishes and low seabird diversity warrant close monitoring.

EXECUTIVE SUMMARY

Ecological integrity refers to indicators that describe individual components within an ecosystem and the relative extent of their potential interactions. We identified and evaluated 40 potential indicators of ecological integrity across a variety of species and foraging guilds, using the ecological literature as a basis for their rankings. We selected indicators that ranked in the top quartile to track two aspects of the California Current Large Marine Ecosystem (CCLME):

- trophic structure: (mean trophic level, scavenger biomass, and the northern copepod biomass anomaly) and
- biodiversity (Simpson's diversity, species richness).

In addition to the indicators reported in this section, indicators on oceanographic features, coastal pelagic- and ground-fishes, and protected species (marine mammals, seabirds, and Pacific salmon) provide information that can influence ecological integrity.

Indicators of Ecosystem Integrity

Short and long-term status of indicators of Ecological Integrity for the California Current Large Marine Ecosystem. Prior to plotting, time series were normalized to place them on the same scale. The short-term trend indicates whether the indicator increased or decreased over the last 5 years of the time series relative to the long-term mean. The long-term axis compares the mean of the last 5 years to the mean of the full time series. Changes or differences of more than 1.0 standard deviation of the full time series (dotted lines) are considered to show an effect. Cop = copepod, Cpel = coastal pelagics, GF = groundfishes, SB = seabirds, anom = anomaly, Rich = species richness, Simp = Simpson diversity, Den = species density, Scav bio = scavenger biomass (GF and crabs), NS = nearshore (0-2 km), shelf=shelf waters (2070 km), s = summer, w = winter.

The spatial extent of CCLME data coverage varies among taxa. The groundfish data span the US west coast ($\sim$ 32-48 ^{o}N, $\sim$50-1200 m) and conclusions related to this data set (mean trophic level, scavenger biomass, species richness, species density, and Simpson diversity) are applicable to the full CCLME. For coastal pelagic fishes, seabirds, and copepods, however, the data analyzed here are currently limited to the northern California Current; future versions of the assessment will integrate data spanning the entire coast.

Status and Trends: Indicators of ecological integrity showed no notable change from their long-term state, but 9 of the 21 indicators showed substantive change over the short-term.

Trophic structure: Trophic structure indicators showed some changes in the CCLME food web. The northern copepod anomaly (winter) increased in the short term, indicating increased abundance of larger copepods and generally good food supply for planktivores in the system. Mean trophic level of groundfishes decreased in the short term indicating a shift in the food web. The decline in mean trophic level was related to decreases in the abundance of Pacific hake and spiny dogfish—both high biomass and high trophic level species. Since many of the higher trophic level groundfishes consume krill and forage fish, lower abundance of these species may make these prey available to other animals in the CCLME. Scavenger biomass and the northern copepod anomaly (spring) showed no appreciable change.

Diversity: Four diversity indicators increased in the short-term: groundfish Simpson diversity, copepod species richness and Simpson diversity in the winter, and Simpson diversity for seabirds on the continental shelf in June. Two indicators decreased in the short-term: seabird species richness and Simpson diversity in near shore waters for birds observed resting on-water.

The increase in Simpson diversity for groundfishes indicates a more even distribution of species within the system and a change in the assemblage structure. While high diversity is generally considered good, the structural changes in the groundfish assemblage require more detailed examination before that conclusion can be reached. The decreases in Pacific hake and spiny dogfish noted above are likely to be the main drivers of increasing Simpson diversity for the groundfishes. Thus while the assemblage is more diverse as species are more evenly represented, the change is due in a large part to a decline in several highly abundant species.

The causes of the decline in seabird diversity on the shelf are not known, but may indicate more recent changes in offshore conditions that have not been detected in other indicators. Increases in diversity of the winter copepod assemblage likely reflect changes in the predominant types of water masses present in the northern California Current region during the winter; planktonic fauna with subtropical neritic and warm–water offshore affinities generally are more species rich.

Future: We propose continuing the development of a fifth indicator in future assessments based on the strong scores of two phytoplankton-related indicators in our evaluation and the important role of phytoplankton in driving biomass production in the upwelling-driven CCLME. We will continue to accumulate, synthesize, and evaluate phytoplankton indicator data-series, including possibly several related to phenology, into 2013. Habitat-based indicators, such as kelp forest coverage, which ranked highly in this evaluation process, will likely form a separate component of the IEA in 2013. Several other indicators warrant more examination in the future, including the biomasses of jellyfish and euphausid. The emergence of several long-term datasets from multiple geographic regions along the coast may strengthen the scores of these indicators in 2013 and provide insight into where we might want to emphasize future data collection efforts. Additionally, we will seek to develop composite indicators for those cases where multiple time series are available (e.g., birds) to simplify the presentation and interpretation of output. Finally, most of the ecological integrity indicators do not have reference points or thresholds, and our evaluation relies upon the internal statistics of the time series. Future work should seek to establish reference points for these indicators.

DETAILED REPORT

BACKGROUND - ECOLOGICAL INTEGRITY

Ecological integrity has been defined as "the ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region" (Parrish et al. 2003). Implicit in this definition is the concept that an ecological system has integrity when its dominant ecological characteristics (e.g., elements of composition, structure, function, and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions. As it is applied in this report, ecological integrity (previously termed ecosystem health in Levin et al. 2011) is defined by indicators of community structure which describe individual components within an ecosystem and the relative extent of their potential interactions. These include community level metrics such as taxonomic diversity, trophic structure and ratios between different foraging guilds, and functional group redundancy and relative biomass. Community composition indicators also include population level trends and conditions across some lower-level trophic levels not typically subject to fisheries, such as zooplankton.

There are numerous publications that cite indicators of ecosystem health or ecological integrity in marine systems. For this report, we generally relied on several core references from the literature to develop an initial list of potential indicators (Jennings and Kaiser 1998, Link et al. 2002, Rochet and Trenkel 2003, Fulton et al. 2005, Jennings 2005, Jennings and Dulvy 2005, Link 2005, Shin et al. 2005, Samhouri et al. 2009, Sydeman and Thompson 2010). In many cases, indicators identified in the literature were chosen by the authors based on expert opinion or the context of the researchers' expertise. For example, many reviews of marine ecosystem indicators are put into the context of fisheries (e.g., Fulton et al. 2005, Link 2005) and ask the question: Which indicators reflect changes in the population as a result of fishing pressure?

INDICATOR SELECTION PROCESS

EVALUATION OF POTENTIAL INDICATORS

We identified and evaluated 40 potential indicators of overall ecological integrity across a variety of taxa and foraging guilds (Table EN1) using the ecological literature as a basis for their rankings (see Levin and Schwing 2011 for detailed methods). Many of the indicators evaluated under the ecosystem health goal in 2011 (Levin and Schwing 2011) were covered under individual fishery or protected species goals in this report (e.g., guild-specific goals such as groundfishes, coastal pelagic species, or marine mammals), and therefore are not addressed in this section to limit report duplication.

Table EN1. Summary of ecological integrity indicator evaluations. The numerical value that appears under each of the considerations represents the number of evaluation criteria supported by peer-reviewed literature. For example, jellyfish biomass status and trends has peer-reviewed literature supporting four out of five primary considerations criteria.

Guild	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Invertebrates	Jellyfish biomass, status and trends	4	3	2	Indicator of trophic energy transfer and pelagic community composition, abundance can be linked to human activities, no existing reference condition. Historical data in CCLME are limited; however, this indicator appears worthy of re-evaluation in 2013 pending review of emerging datasets that may strengthen data considerations.
	Squid, Humboldt	1	2	2	Range expansion correlated with reduction in top predators; possibly indicates shifts in climate regimes, ocean circulation, and ecosystem-wide food webs; data minimal and of limited spatial and temporal scale.
	Crustaceans: catch and survey trends	4	5	4	Indicative of community regime shift: high trophic level groundfish to low trophic level crustaceans; often attributed to climate induced changes in water column temperature and fishing; multiple data sources available, including larval abundance
	Benthic invertebrate biomass	5	3	0	Correlates well with ecosystem health and responds to fishing pressure; some databases available, although depth strata and sampling design not readily apparent; gradual change should show major community reorganization
Zooplankton	Zooplankton abundance and biomass	4	7	5	Base of food web, fundamental component of CCLME, correlated with regime shift and climate change, can be used to estimate thresholds, several ongoing long-term data sets.
	Copepod biomass anomalies	5	7	5	Reflect modifications in water masses, currents, or atmospheric forcing; respond rapidly to climate variability; some taxa reflect influence of different water types on ecosystem structure; data availability as above.

Guild	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Zooplankton (cont.)	Euphausid biomass and richness	5	2	3	Indicator of plankton biomass changes, critical link in marine food web, low counts and high patchiness in samples may increase variability, data availability appears to be improving; expect improved evaluation in 2013.
Diversity indices	Species richness	2	6	3	Can provide a useful measure of diversity if the study area can be successfully delimited in space and time; simple to interpret; may not be highly sensitive to change or management actions; data available from groundfish, zooplankton, benthic invertebrate surveys.
	Hurlbert's delta (evenness)	4	7	2	Reflects taxonomic evenness; calculated from abundance estimates; change detectable with latitude and depth at large scales; natural and baseline levels of evenness may vary; significance of certain types of change not known; data available from groundfish, zooplankton, benthic invertebrate surveys.
	Simpson Diversity Index	4	7	3	Theoretically sound, calculated from abundance estimates; difficulty linking diversity indices to targets or reference points; numerical; does not show bias in mean value in relation to number of individuals in a sample; for data availability see Hurlbert's biodiversity index above.
	Shannon Diversity	4	5	2	Measures taxonomic richness and evenness, community stability related to higher diversity, difficulty linking diversity indices to targets or reference points, for data availability see Hurlbert's biodiversity index above.
	Taxonomic distinctness (average and variation in)	3	6	1	Uses species lists, not abundance data; minimal data requirements allows integration of data sets, use of historical data, and data of varying quality; for data availability see Hurlbert's biodiversity index above.
	Number of threatened species (IUCN A1 criteria)	4	5	1	Composite indicator based on weighted average of species threat, criteria somewhat arbitrary, linking index to targets or reference points is difficult, data available and numerical.

Guild	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Trophic structure	Mean trophic index / mean trophic level	3	6	4	Much recent discussion of this indicator in the literature. Ecosystem MTL, which is calculated from available fisheries independent data, will correctly track changes in the trophic structure of the ecosystem. Internationally recognized; provides both leading and lagging guidance.
Functional groups	Top predator biomass (trophic level > 4.0)	5	2	4	Top predator removal typically results in trophic cascades. Data available for many groundfish and seabird top predators, but data for sharks and marine mammals are less reliable.
	Invertivore biomass	2	7	2	Correlated with several measures of diversity and total biomass in modeling exercises, but variation in community composition may not be detected by variation in this functional group alone.
	Detritivore biomass	3	7	2	Similar comment as above.
	Herbivore biomass	3	7	2	Similar comment as above.
	Scavenger biomass	4	7	2	Some evidence that disturbances, such as fishing activities, induce chronic increases in scavenger populations, but changes in this one functional group may (or may not) be indicative of the entire community.
Biomass ratios	Forage fish and jellyfish biomass ratio	3	2	1	Highly correlated with diversity measures and mean trophic level in modeling exercises. Data limited for both groups; ratios of functional groups are not easily understood indicators.
	Piscivorous and Zooplanktivorous fish biomass ratio	2	0	2	Highly correlated with diversity measures in modeling exercises, but how many species have data available is unknown.

Guild	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Biomass ratios (cont.)	Pelagic and demersal fish biomass ratio	2	1	2	Appears to be a proxy for differential impact of nutrients on the pelagic and benthic food webs based on modeling exercises.
	Zooplankton and phytoplankton biomass ratio	3	1	1	Highly correlated with measures of diversity and mean trophic level in modeling exercises, but data are particularly limited for phytoplankton, although proxies such as chl-a have been used.
	Rockfish and flatfish biomass ratio	3	7	1	Highly correlated with measures of diversity and total biomass in modeling exercises.
	Invertivore and herbivore biomass ratio	1	7	1	Similar to comment above.
	Finfish and crustacean biomass ratio	3	7	1	Indicative of community regime shift in several systems from high trophic level groundfish to a low trophic level, crustacean-dominated system; see comments above under crustacean and groundfish biomass and survey trends for data availability.
Fishery catch	Trophic level of catch (mean biomass)	2	1	0	Shortcomings associated with typical catch-based data; size-based indicators are better because they do not require diet data, are less error prone, and more easily collected.
	Proportion noncommercial species (unfished groups)	3	4	2	Modeling results show response to variation in fishing pressure and correlation with ecosystem attributes, one of the more sensitive indicators of changes in species composition.
	Total catch and landings of target species	2	4	1	Considered good indicator of fishing effects but poor indicator of marine ecosystem performance, primarily a function of fishing effort and a poor approximation of production, landings can be misleading in assessments ecosystems.

Guild	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Fishery catch (cont.)	Total fishery removals of all species (including bycatch)	3	3	1	See above, bycatch data often not recorded.
	Total fishery removals of all species	2	6	2	See above.
	Mean length, all species	3	1	4	Useful and simple indicator to evaluate effects of fishery removals, but may not be observable over short-term monitoring data sets.
	Slope size spectrum, all species	2	1	1	Good indicator of fishing effects, models show change is predictable and consistent, unclear what attributes it would act as an indicator for besides general ecosystem health, thresholds unclear, size data sparse for some species.
Habitat species	Kelp forest coverage	4	5	5	Kelp forests occur at small scales compared to the entire California Current, so overall ecosystem structure may not be tied to kelp coverage, but these are important habitats for recruitment of important species. Likely habitat-based indicator for future assessments.
	Area of live, hard coral	5	2	2	Similar comment as above. Data on spatial extent of coral cover are limited.
Phytoplankton	PPC:PSC ratio (carotenoid ratio)	2	3	0	Ratio of photosynthetic pigments (PSCs), such as chlorophyll and some carotenoids, to photoprotective carotenoids (PPCs); ratios can be used to detect areas of upwelling. Limited history of reporting; not well-understood by public or policymakers.

Guild	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Phytoplankton (cont.)	Diatom: dinoflagellate ratio	1	4	0	Ratio of diatoms to dinoflagellates, which can be related to copepod production and hatching success/survival. Time-consuming method based on direct microscope counts. Phytoplankton cell counts have been taken on all CalCOFI cruises since 2002. Limited history of reporting.
	Community structure - pigments	3	4	0	Robust method to identify pigment compounds specific to different microalgae and thereby estimate composition of phytoplankton community; implications for energy cycling. Some limitations in understanding of community controls remain. Phytoplankton pigments have been surveyed on all CalCOFI cruises since 2002.
	Community structure - cell counts	3	5	2	Taxonomic structure has implications for ecosystem function and energy cycling; time-consuming method based on direct microscope counts, phytoplankton cell counts have been taken on all CalCOFI cruises since 2002.
	Biomass – Chl-a	4	5	3	Good indicator of phytoplankton biomass and amount of energy fueling the ecosystem, satellite remotely sensed chlorophyll concentration data available system wide; spatially and temporally variable; rarely reported as a single indicator value

TOP RANKED INDICATORS

What follows is a general description of the indicators ranked in the top quartile (10 indicators), as well as several others making a strong showing and with future potential. Weighted numeric ranks are noted in parentheses after each indicator name, with rank ties indicated by the letter (T). General categories of indicators are grouped by the taxa or processes they represent, and include: Biodiversity, Trophic structure, Zooplankton, Phytoplankton, and Other. A summary of all 40 of the indicator evaluations is provided in Table EN1, including the number of evaluation criteria supported by the peer-reviewed literature and some brief comments.

Zooplankton were represented by two of the top-ranked indicators, with four indicators of biodiversity and two of trophic structure also represented in the top quartile. In general, the initial ranking process retained the same pool of indicators as after weighting the evaluation criteria based on expert opinion. Exceptions include *scavenger biomass* and some of the diversity indicators (i.e., *Shannon diversity* and *number of IUCN threatened species*) which jumped into the top quartile after weighting, and *species richness* and two phytoplankton indicators (i.e., *phytoplankton community structure* and *Chl-a / phytoplankton biomass*) which fell out of the top quartile. Shortcomings of the two phytoplankton indicators were primarily due to weak links to scientifically-defined reference points or progress targets, poor understanding of temporal and spatial variation, and lack of understanding by the public and policymakers.

Indicators that scored well under primary considerations generally included foraging guild trends and biomass. Many functional group ratios have been identified by modeling exercises as good indicators of diversity and total biomass in the system. However, a common theme for many of these indicators was that they performed poorly for criteria related to their responsiveness and sensitivity to changes in community composition. This is because changes in species' or foraging guilds' trends and abundance will influence community composition and ecosystem structure, but changes in community composition may not be reflected in any one species or foraging guild. Moreover, it is conceivable that many of the foraging guild ratio indicators (e.g., piscivorous to zooplanktivorous fish ratio) could have scientifically defined reference points and progress targets, but these ratios may not be easily understood by the public and policy makers. Furthermore, changes in many of these community-level metrics cannot be observed in short-term monitoring sets and may be more useful at longer management time scales (Nicholson and Jennings 2004).

Most of the indicators related to fishery catch scored well with regard to data considerations, but rarely met primary considerations associated with being theoretically sound or predictably responsive. This could be attributed to the often misleading nature of landings in assessments of fisheries ecosystems (de Mutsert et al. 2008) and weak showing as indicators of marine ecosystem performance in food web model simulations (Samhouri et al. 2009). In contrast, several indicators showed promise by meeting most theoretical considerations (e.g., *jellyfish* and *euphausid biomass*) but often lacked adequate historic data over a broad geographic scale.

ZOOPLANKTON

Two of the three zooplankton-related community indicators ranked among the highest of the 40 indicators that were evaluated.

ZOOPLANKTON SPECIES BIOMASS ANOMALY (NORTHERN COPEPOD BIOMASS) (1)

Zooplankton time series provide some of the best opportunities to understand marine ecosystem responses to climate change because zooplankton are the foundation of the ocean food web, linking oceanographic conditions and primary production to upper trophic levels and fueling the delivery of ocean ecosystem services. Zooplankton life cycles are short (on the order of weeks to a year) and populations have the potential to respond to and reflect event-scale and seasonal changes in environmental conditions (Hooff and Peterson 2006). Moreover, many zooplankton taxa are known to be indicator species whose presence or absence may represent the relative influence of different water types on ecosystem structure. Thus zooplankton may serve as sentinel taxa that reflect changes in marine ecosystems by providing early indications of a biological response to climate variability and are often used as an indicator to detect climate change or regime shifts (Hooff and Peterson 2006, Mackas et al. 2006, Peterson 2009). Finally, zooplankton are abundant and can be quantified by relatively simple and comparable sampling methods and, because few are fished, most population changes can be attributed to environmental causes (Mackas and Beaugrand 2010). As such, they may prove useful as a leading indicator of what may happen to regional commercial fish stocks several years later (Mackas et al. 2007, Peterson et al. unpubl. manuscr.).

All along the California Current, anomalies in zooplankton species composition shifts have been correlated with regional climate patterns (Mackas et al. 2006). For example, off the Oregon coast zooplankton indices have been developed based on the affinities of copepods for different water types: those with cold water and those with warm water affinities (Peterson et al. unpubl. manuscr.). The cold water group usually dominates the coastal zooplankton community during the summer (typically May through September) upwelling season, whereas the warm water group usually dominates during winter, although this pattern is altered during summers with El Niño events or when the Pacific Decadal Oscillation (PDO) is in a positive (warm) phase. Perhaps the most significant aspect of the copepod index is that two of the cold water species, *Calanus marshallae* and *Pseudocalanus mimus*, are lipid-rich species. Therefore, an estimate of northern copepod biomass may also index the amount of wax esters and fatty acids being fixed in the food chain, compounds which appear to be essential for many pelagic fishes if they are to grow and survive through the winter successfully.

Several long-term zooplankton monitoring programs, representing seven subregions spanning the entire CCLME from Baja California to Vancouver Island, now provide zooplankton time series of various lengths from 1969 to the present. Although differences in processing and sampling zooplankton time series introduce a variety of biases that often prevent comparisons between data sets, many major questions can still be answered because an individual data set can be presented and analyzed as a time series of log-scale anomalies relative to the local long-term-average seasonal climatology. Anomalies are primarily used to separate interannual variability from the often large annual seasonal cycle of zooplankton stock size (Mackas and Beaugrand 2010). The specific species associated with these anomalies vary regionally, but can generally be classified as resident versus nonresident species. Regional anomalies can be combined into a single index using multivariate techniques (e.g., principal component analysis) in similar fashion to the calculation of regional climate indices, such as the Multivariate El Niño Southern Oscillation (ENSO) Index (Wolter and Timlin 1993). This index can then be tested for use as a leading indicator of regional climate signals, such as ENSO or PDO, using existing time series from the last 20 years, during which time the California Current saw at least two major climate regime shifts.

ZOOPLANKTON ABUNDANCE AND BIOMASS (2)

As noted above, zooplankton time series provide some of the best opportunities to understand marine ecosystem responses to climate change. As an important link at the base of the pelagic food web, they are considered a fundamental component in the CCLME (Brand et al. 2007, Horne et al. 2010, Sydeman and Thompson 2010). Because the biomass of planktivorous fish is inversely related to zooplankton biomass, which in turn is inversely related to phytoplankton biomass, zooplankton may prove useful as a leading indicator of what may happen to regional commercial fish stocks several years later (Sherman 1994, Mackas et al. 2007, Mackas and Beaugrand 2010, Peterson et al. unpubl. manuscr.). Zooplankton biomass declines have been correlated with warming of surface waters (Roemmich and McGowan 1995, Sydeman and Thompson 2010) and used to detect regime shifts (Hare and Mantua 2000). However, for time series observations of ecosystem state variables such as biomass or chemical concentrations, standard deviations may increase, variance may shift to lower frequencies in the variance spectrum, and return rates in response to disturbance may decrease prior to a change (Carpenter et al. 2008).

The feeding effect of pink salmon (*Oncorhynchus gorbuscha*) has been shown to control summer macrozooplankton and phytoplankton biomass in the subarctic North Pacific (Shiomoto et al. 1997). Trophic cascade theory holds that reductions in harvest of zooplanktivorous fish would ultimately result in lower biomass of zooplankton, but it is unclear whether this has been demonstrated in the field for large marine systems (Pace et al. 1999). There are a number of (up to seven) long-term zooplankton biomass time series that have been maintained throughout various regions of the CCLME (Hooff and Peterson 2006, Mackas and Beaugrand 2010); one of the oldest of these data sets is the California Cooperative Oceanic Fisheries Investigative (CalCOFI) reports time series, which has been collected since 1956 (McClatchie et al. 2009). In freshwater systems, zooplankton biomass has been used as a leading indicator of trophic cascades (Carpenter et al. 2008).

BIODIVERSITY

Species diversity is an integrative measure that encompasses species richness - the number of species in the ecosystem, and species evenness - how individuals or biomass are distributed among species within the ecosystem (Pimm 1984). Diversity has remained a central theme in ecology and is frequently seen as an indicator of the wellbeing of ecological systems (Magurran 1988). It is therefore not surprising that four diversity-related indicators ranked in the top quartile of our evaluation.

Theoretical modeling results have been used to show that some ecosystem structural (e.g., diversity) attributes can be related to thresholds in the level of human-induced pressure. The correlation between diversity and ecosystem function (productivity and stability) has been reviewed recently for terrestrial and marine systems, suggesting that the relationship is complex but communities are more stable at higher richness (Hooper et al. 2005, Stachowicz et al. 2007). In general, populations can be more variable but community level processes are more stable at higher diversity (i.e., the biomass of species A and species B may fluctuate, but A + B tends to be stable). Linking diversity indices to targets or reference points is difficult, and the significance of certain types of change is not known for biodiversity indices (Link 2005, Dulvy et al. 2006). However, some authors have provided a rationale to manage for biodiversity as an approach to EBM (Palumbi et al. 2009). The general public tends to have a basic understanding and positive impression toward biodiversity as it relates to ecosystem health (Thompson and Starzomski 2007). Species richness has been shown to decrease with fishing, although these results appear largely related to trawling and dredging on benthic invertebrates (Gaspar et al. 2009, Reiss et al. 2009).

All of the following diversity indices can be used with a variety of existing survey data, including: groundfish trawl surveys (Weinberg et al. 2002, Keller et al. 2010), pelagic or midwater trawl surveys (Brodeur et al. 2003, Sakuma et al. 2006), reef fish surveys conducted by trained divers (REEF 2008), zooplankton surveys (e.g., NWFSC Newport Line, CalCOFI), invertebrates from benthic grabs conducted by the EPA (http://www.epa.gov/emap/index.html), and a variety of seabird and marine mammal surveys (Ainley et al. 1995, Barlow and Forney 2007, Carretta et al. 2007, McClatchie et al. 2009). Other possible data sources include intertidal invertebrate surveys from 2002 to 2010 (PISCO at http://www.piscoweb.org/) and datasets available at smaller spatial and temporal scales (e.g., National Park Service kelp forest monitoring program in the Channel Islands). Many of these data would need to be combined to investigate trends over time across the entire scale of the CCLME.

SIMPSON'S INDEX OF DIVERSITY (3)

Simpson's index is a dominance measure that estimates the probability that any two individuals drawn at random from an infinitely large community would belong to different species (Magurran 1988). It is similar to Hurlbert's (1971) concept of the probability of an interspecific encounter when individuals are drawn with replacement, and is relevant to predator-prey and food-web analyses. It is a numerical measure and does not show bias in mean value in relation to the number of individuals in a sample (Clarke and Warwick 2001). Model simulations, used to evaluate the ability of candidate indicators to track ecosystem attributes of interest, have shown that Simpson's diversity was strongly correlated to the biomass of marine mammals in a system. Samhouri et al. (2009) notes that the indicator-attribute relationship can switch depending upon the type of fishing pressure used in the model. This result might make the indicator-attribute relationship unpredictable in the real world.

EVENNESS (HURLBERT'S DELTA) (4)

Hurlbert's delta is a measure of evenness that, when applied to abundance estimates from a particular ecological community, estimates the probability of an interspecific encounter: that two individuals in a sample are different species (Hurlbert 1971). It has a clear, concise ecological interpretation and is relevant to predator-prey and food-web analyses and has been applied as an indicator for detecting the impact of fishing on a fish community (Trenkel and Rochet 2003). Hurlbert's delta measure has been applied in measuring detectable spatial variation with depth and latitude at large scales and, although temporal patterns may be unknown, could be calculated from historical data (Tolimieri 2007). It can also be used to detect changes in community composition after change has occurred, although natural and baseline levels of taxonomic evenness may vary so much that absolute values may not be comparable in terms of thresholds.

SHANNON DIVERSITY (9-T)

Shannon diversity is a measure that incorporates both richness (the number of different species within a system) and evenness (the number of individuals of each species within a system). A marine ecosystem model for British Columbia showed that adult sablefish biomass was positively correlated with Shannon diversity, suggesting that changing levels of fishing on a particular species may produce substantial improvements toward protecting ecosystem goals based on this structural attribute (Samhouri et al. 2010). The model also describes how to incorporate uncertainty into the estimation of utility thresholds and their value in the context of understanding EBM trade-offs. These modeling results may be equally applicable to the CCLME because of many similarities between these ecosystems. The value of this indicator is predicated not only on the correlation between sablefish biomass and ecosystem diversity, but also on how well each of these independent indicators meet individual evaluation considerations.

NUMBER OF THREATENED SPECIES (IUCN A1 CRITERIA, AS MODIFIED BY DULVY ET AL. (2006) (9-T)

This is a composite indicator based on a weighted average of species threat, as determined by the International Union for the Conservation of Nature (IUCN 2008), which may be different from those considered threatened under the U.S. Endangered Species or the Marine Mammal Protection acts. The weighting criteria for this indicator are somewhat arbitrary and linking the index to targets or reference points is difficult; however, data are readily available and numerical. The same approach used by the IUCN could be applied to a variety of existing survey data.

SPECIES RICHNESS (15)

Species richness, which is a count of the number of species present, can provide an extremely useful measure of diversity if the study area can be successfully delimited in space and time and the constituent species enumerated and identified (Magurran 1988). Though ranked low in the evaluation, we included a description here because species richness can be used to help inform other standard measures of diversity. Species richness may not be highly sensitive to change and may not respond unambiguously to variations in ecological integrity or management action; furthermore, the species--sampling intensity relationships will require rarefraction to standardize for sampling effort. Studies have shown that species richness tends to decline with fishing, primarily based on trawling/dredging effects on benthic invertebrate communities (Gaspar et al. 2009, Reiss et al. 2009).

Richness can influence stability and productivity in two ways: 1) sampling/selection effect or 2) compensatory effect (Stachowicz et al. 2007). Under the sampling effect, higher richness leads to a greater chance of highly productive species being present. This type of relationship is not considered a real richness effect by some, but more of a compositional or keystone species effect. Under the compensatory effect, higher production or stability occurs in two ways: via resource complementarity, where more species occupy more niches and better utilize all resources (e.g., different type of nitrogen), and facilitation, where some species combinations do better.

TROPHIC STRUCTURE

Organisms within an ecosystem can be classified according to their trophic level, or position within the food web (e.g., functional groups include herbivores, carnivores or predators, detritovores, and scavengers), and indicators of trophic structure attempt to measure their relative abundance, biomass, and interactions. Indicators related to the biomass of specific trophic levels within the ecosystem ranked highly in the evaluation, especially within the context of theoretical or practical considerations.

SCAVENGER BIOMASS (5)

Scavengers play significant roles in the ecosystem by recycling dead and decomposing organic matter back into the food web. However, human interference in the marine ecosystem has likely increased the abundance and number of species that forage on carrion (Britton and Morton 1994). For example, many fishing operations discard dead bycatch to the ocean floor or damage organisms on the seabed during bottom fishing operations (Ramsay et al. 1998). Scavenger population increases may be related to these types of fishing activities (Britton and Morton 1994, Ramsay et al. 1998, Demestre et al. 2000).

When evaluating this indicator, we use the definition of scavenger used in the Atlantis ecosystem models for the California Current (Brand et al. 2007, Horne et al. 2010). In these models, scavengers include all large crabs, large demersal sharks, grenadiers, deposit feeders (i.e., isopods and amphipods), and carnivorous infauna such as polychaetes. Detectable changes in the community composition may be a result of changes in various foraging guilds, but a change (or no change) in a single guild may not be indicative of the ecosystem as a whole. Fisheries-based reference points include B40 (target level where production is predicted to be greatest) and B25 (overfished). These single-species reference points could be adapted and used for foraging guilds such as scavengers. Alternatively, Link (2005) describes a framework of reference points that could be applied to most any indicator.

Fishery-independent data are available since 1977 for all scavenger species susceptible to bottom trawling across the U.S. portion of the CCLME. There are also data available at smaller spatial scales and at various temporal scales in untrawlable habitats from submersible, ROV, and the NWFSC hook-and-line surveys. Fishery-dependent data for crab species are available in the PacFIN database (http://pacfin.psmfc.org/). Some species of the scavenger guild, such as isopods, amphipods, and polychaetes, will need new surveys to quantify these components. Benthic grab samples are commonly used to quantify benthic infauna, but it may be difficult to perform this type of survey at the scale of the CCLME at necessary temporal scales. Moreover, quantifying a value for many foraging guilds will require quantitative analyses to combine data sets which collect data using very different methods. For example, bottom trawl surveys, longline surveys, and benthic grab samples will need to be combined at various spatial and temporal sampling scales to quantify the biomass of grenadiers, crabs, large demersal sharks, and deposit feeders.

The public can easily understand whether a foraging guild, such as scavengers, is trending up or down, but this particular indicator may be less attractive to the public than more charismatic groups (i.e., marine mammals or sharks). Detecting changes in the biomass of scavengers would likely be measured against long-term averages, so unless dramatic changes are observed, scavenger biomass will be a lagging indicator of changes in community composition. Monitoring foraging guilds such as scavengers has been performed in other regions of the United States (Link and Almeida 2002) and in other nations (Demestre et al. 2000, Greenstreet and Rogers 2000).

MEAN TROPHIC LEVEL (6)

Mean trophic level (MTL) is the biomass-weighted average trophic level of all species in an ecosystem. Mean trophic level provides a synoptic view of the organization of trophic structure in marine ecosystems, and is a pervasive and heavily discussed indicator used to measure marine ecosystem status, especially in communities dominated by exploited species (Pauly and Watson 2005, Essington et al. 2006, Branch et al. 2010). Conceptually, MTL is linked to top-down control and trophic cascades; a decline in MTL represents a decrease in the ability of predators to 'control' prey populations and may have far-reaching consequences to ecological communities (Daskalov 2002, Estes et al. 2004, Pauly and Watson 2005, Baum and Worm 2009). Theoretical modeling results have been used to show that mean trophic level can be a good univariate indicator of fishing effects on an ecosystem, although it may be sensitive to data quality (e.g., landings v. survey data) (Fulton et al. 2005, Samhouri et al. 2009). Trends in 'catch' MTL, estimated from fisheries landings and other fishery dependent data sources may not provide a good indicator of actual changes in the ecosystem. Instead, 'ecosystem' MTL, estimated from data sources like fisheries-independent surveys, is indicative of current ecosystem status especially when coupled with an exploration of the processes responsible for such patterns (Branch et al. 2010).

Mean trophic level is an operationally simple, concrete, numerical indicator, calculated each year using the simple mean of biomass weighted trophic levels within an ecosystem. Trophic levels can be estimated for species worldwide from an online data base (http://www.fishbase.org/search.php); species biomass can be obtained from historical, annual estimates derived from standardized surveys throughout the California Current (various groundfish, zooplankton, marine mammal, and seabird survey, etc.). These surveys are generally continuous, have broad spatial coverage, and are designed with appropriate power to have a high signal-to-noise ratio (for most species). The spatial temporal variation in these time-series is becoming increasingly understood as more data are collected each year.

Mean trophic level is included in the list of provisional indicators for assessing progress toward the 2010 biodiversity target, proposed by the Convention of Biological Diversity (http://www.cbd.int/). As such, it is understood by the public and policymakers, considered internationally compatible, and demonstrates a relatively recent history of reporting (Pauly and Watson 2005, Stergiou and Tsikliras 2011). Mean trophic level can be estimated in a cost-effective manner using existing survey data (various groundfish Stock Assessments, REEF.org, etc.). Mean trophic level may fill a role as a leading indicator because the concept of MTL is closely related to top-down forcing and trophic cascades. As such, changes in the trophic structure revealed by MTL may predictably preface changes to other taxa (unpublished data, N. Tolimieri).

PHYTOPLANKTON

Two phytoplankton indicators fell just outside of the top quartile rankings in our evaluation. Phytoplankton indicators in general tended to meet most theoretical considerations, based on taxonomic structure and biomass, the latter of which performed particularly well under simulations involving seven marine food web models (Samhouri et al. 2009). Because phytoplankton forms the base of the food web for most pelagic communities and drives biomass production in the upwelling-driven California Current marine ecosystem, we strongly suggest continuing the search or development of a more appropriate phytoplankton indicator in future evaluations, perhaps by inclusion of indicators related to phytoplankton phenology.

PHYTOPLANKTON BIOMASS – CHLOROPHYLL-A (12)

Chl-*a* can be used as an indicator of phytoplankton biomass, which itself is a good indicator of the amount of energy fueling the ecosystem (Falkowski and Kiefer 1985, Cole and Cloern 1987, Polovina et al. 2001, Edwards and Richardson 2004, Fulton et al. 2005). The amount of primary productivity, measured as total chlorophyll per unit area (mg m^{-3}), has been recognized as an important aspect of the marine food web, and Chl-*a* values are used to estimate phytoplankton biomass for mass-balance models of the CCLME (Falkowski and Kiefer 1985, Brand et al. 2007, Horne et al. 2010). Chl-*a* has been shown to respond predictably to reductions or increases in nutrient inputs (eutrophication). It should be possible to identify time-specific and location-specific reference points for upwelling or transition fronts.

Chl-*a* has been used to provide basic data for CCLME ecosystem model building and calibration based on values from GLOBEC sampling cruises between 1997 and 2004 and CalCOFI cruises from 2000 to 2004 (Brand et al. 2007). Satellite remotely sensed Chl-a concentration (mg m^{-3}) data can be obtained at minimal cost from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS at http://oceancolor.gsfc.nasa.gov/SeaWiFS/) to derive broad-scale coverage of values over the CCLME (Polovina and Howell 2005) or at smaller regional scales (Sydeman and Thompson 2010). Phytoplankton color, a visual index of chlorophyll derived from continuous plankton recorder (CPR) surveys (http://www.sahfos.ac.uk/about-us/cpr-survey/the-cpr-survey.aspx), can also be used to show intensity and seasonal extent of Chl-a (Edwards and Richardson 2004). However, the relationship between reflectance and phytoplankton biomass must be derived and

requires ground-truthing studies. Some species or subsets of species of phytoplankton that affect Chl-a concentration can serve as an indicator of change in phytoplankton biomass, but physical measurements of upwelling intensity may provide a better leading indicator. The approach for compressing the temporal and spatial variability of this information into a single datum presents challenges, however.

PHYTOPLANKTON COMMUNITY STRUCTURE – CELL COUNTS (13)

The taxonomic structure of phytoplankton communities is an important determinant of ecosystem function, with far-reaching implications for the cycling of energy and matter in the marine environment (Goericke 2011). In the California Current, the phytoplankton community changes predictably as total chlorophyll a (TChl-a) increases in the system, a pattern driven by increasing nutrient loading or nutrient content. Time series of specific phytoplankton taxa reflect the short term variability of phytoplankton biomass, which is likely controlled by varying rates of nutrient-autotroph and autotroph- heterotroph interactions (Mackey et al. 1996, Goericke 2011). Reference limits have been established that provide a general relationship of Chl-a to phytoplankton community structure and as an early indicator that can differentiate and identify bloom assemblages.

Total phytoplankton biomass is generally limited by the availability of a critical nutrient (i.e., by bottom-up forces), but the biomass of some taxa, particularly picoautotrophs, is controlled by grazers (i.e., top-down forces) under mesotrophic to eutrophic conditions. The distribution of cyanobacteria suggests that their population dynamics are not tightly linked to the dynamics of their grazers, likely because the latter are grazing concurrently on heterotrophic bacteria (Goericke 2011). However, there are some noted limitations in our understanding of the controls of phytoplankton community: data sets from southern California suggest that nearshore communities may differ fundamentally from coastal oceanic communities, and temperature may exert important secondary effects on phytoplankton community structure based on cyanobacteria distributions (Thomas and Strub 2001). Variability of autotroph biomass in the California Current is primarily due to blooms of dinoflagellates and to some extent diatoms, i.e., the larger autotrophs that contributed 81% to the variability of TChl a over time (Goericke 2011).

Phytoplankton samples, complemented by complete hydrographic data, have been routinely taken on CalCOFI cruises from at least 2002-present. The California Current Ecosystem – Long Term Ecological Research (CCE-LTER) program collects samples for nano and microplankton identification and sizing using microscopy, and for picoplankton using flow cytometry, providing additional information on community. Two permanent sampling lines (#90 and 80) are sampled extensively for micro/nano/pico plankton, plus mesozooplankton; line 80 is off Point Conception and line 90 is near Catalina and San Clemente Islands. Each line has 8 stations, with 4 cardinal stations that are always sampled at multiple depths. Additional data is also available from smaller, geographically limited projects such as WEST (May-June 2000-2002), RISE (May-August 2004-2006), and EcoHAB (July-Sept 2003-2006). These projects have detailed phytoplankton community composition data which are compatible with the CalCOFI pigment groupings. Continuous historical data is limited to the CalCOFI sampling area, which extends from southern California to central California. Data from CalCOFI samples is available from at least 2002 to the present. Data from central CA is available from 2000-2002 and data from WA/OR coast is available from 2003-2006. Seasonal succession and patterns of bloom/post-bloom communities is fairly well understood. Spatially, features like the Columbia River Plume are known to influence communities on the WA/OR coasts, as are upwelling areas, such as Pt. Conception on the CA coast (Thomas and Strub 2001)

This indicator would be considered cost-effective because data is already collected as part of CalCOFI and CCE-LTER. Phytoplankton community structure, would be considered an anticipatory indicator of

conditions in the California Current (Gallegos 1992, Macedo et al. 2001, Nuccio et al. 2003). These techniques have been applied successfully in many locations from the Antarctic to the Equator (Mackey et al. 1996).

OTHER INDICATORS

Other indicators in or near the top quartile included those related to fishery catch, invertebrate surveys, and habitat distributions.

CRUSTACEAN SURVEY TRENDS (7-T)

Crustaceans are a prominent component of the CCLME and contribute to the delivery of several important ecosystem services in the region through commercially and recreationally important fisheries (Fogarty and Botsford 2006). They also comprise several important predatory and scavenger groups in existing CCLME models (Brand et al. 2007). They are highly responsive to top-down effects in the food web, and predatory finfish abundance may be a negative indicator for invertebrate fishery productivity (Caddy 2004). For instance, shrimp biomass has been strongly negatively related to cod biomass in the North Atlantic Ocean, showing that changes in predator populations can have strong effects on prey populations in oceanic food webs (Worm and Myers 2003). Fishing effects may exacerbate these patterns: the Gulf of Maine shifted from a high trophic level, groundfish-dominated, system to a low trophic level, crustacean-dominated system during the 1980s to 1990s (Zhang and Chen 2007).

As a group, crustaceans are often found low in the food web, are highly fecund, and may be sensitive to bottom-up effects; therefore, indicators measuring plankton productivity, turbidity, oxygen levels, and eutrophication should be useful in predicting the typically large variations in recruitment success that drive these fisheries (Caddy 2004). Climate change manifested in water column temperature also has an effect on lower trophic levels of boreal marine ecosystems, and changes in crustacean recruitment patterns may be one of the first indicators of community regime shift (Zheng and Kruse 2000). For instance, declines in several species of pandalid shrimp and other community effects in the Gulf of Alaska have been attributed to climate induced changes in water column temperature (Anderson 2000). Pandalid shrimp surveys are also used as indicators of Pacific Ocean conditions off British Columbia (DFO 2009). The abundance of decapod larvae in the plankton also appears to be positively correlated to changes in North Sea sea surface temperature (SST) (Kirby et al. 2009).

For the most part, data availability for this group is relatively good. Zooplankton time series are spatially and temporally extensive (Mackas et al. 2007, McClatchie et al. 2009) and crustacean larval surveys represent a long established means of estimating the spawning stocks of decapods (Kirby et al. 2009). Harvest data records are fairly extensive through PacFIN (though biased by typical catch issues) and some aspects of the ongoing West Coast groundfish surveys may be useful in deciphering abundance/biomass patterns (Keller et al. 2008).

KELP FOREST COVERAGE (7-T)

Kelp forests are ecologically and economically important, as they are the foundational structure for diverse communities in most coastal waters of the CCLME (Dayton 1985, Graham 2004). The persistence of many biologically and commercially important species of algae, invertebrates, fish, and marine mammals are directly coupled to the production of energy from kelp (Foster and Schiel 1985, Steneck et al. 2002). Kelp forests may also serve functional roles in cycling carbon between coastal marine, littoral (Polis and Hurd 1996, Dugan et al. 2003), and continental shelf (Harrold et al. 1998, Vetter and Dayton 1999) ecosystems.

Most kelp forests exist in waters less than 60 m deep, so at the scale of the CCLME community composition may not be tied to the abundance of kelp, but because of its importance as essential fish habitat for many species of concern, including young-of-year fishes (Carr 1991), understanding the temporal variation and spatial heterogeneity (Jones 1992, Bustamante and Branch 1996) of kelp forest coverage in the CCLME may be a useful indicator of ecosystem structure. Following the framework of Link (2005), reference points related to percent change in aerial coverage of kelp could be established.

The density and distribution of kelp forests has been measured historically in numerous ways. Many historical data sets include scuba diving surveys (e.g., Partnership for Interdisciplinary Studies of Coastal Oceans [PISCO] at http://www.piscoweb.org/, U.S. National Park Service at http://www.nps.gov/chis/contacts.htm), but these are generally over small spatial and short temporal scales. Recent advances in satellite and infrared photography have allowed researchers to measure areal canopy cover and biomass of kelp along much of the U.S. West Coast (Deysher 1993, Cavanaugh et al. 2010).

Kelp forest coverage is easily understood by the public and has been used by policy makers to develop guidelines related to provisions of the marine statistical area on the identification of essential fish habitat (16 U. S. C. §1855b). Changes in kelp forest coverage affect recruitment of invertebrates and other species (e.g., Carr 1991), such that kelp forest coverage could anticipate recruitment of older life stages into the bottom trawl surveys or into the fishery. Kelp forest coverage could be a leading indicator for the community composition of the CCLME and will be considered under a separate habitat goal category in forthcoming IEAs.

PROPORTION OF NONCOMMERCIAL SPECIES (9-T)

The proportion of noncommercial species in fishery catch data has been shown to be strongly related to 12 attributes of ecosystem health, based on modeling results from numerous systems (Samhouri et al. 2009). It has been used as one of the more sensitive indicators for detecting the impacts of fishing on fish communities, with a coefficient of variation around 20% for either biomass or abundance (Trenkel and Rochet 2003). Modeling results show the proportion of noncommercial species responds to variation in fishing pressure and correlates to ecosystem attributes (Samhouri et al. 2009). If this indicator is monitored, gradual change should be detected prior to major community reorganization (i.e., leading indicator). Data for this indicator include a limited number of time series with good spatial coverage: Marine Recreational Fisheries Statistics Survey (MRFSS 1980–2003), data for nontrawl species (http://www.recfin.org/), and data from the observer program (bycatch species) (Bellman et al. 2009). However, in the limited entry bottom trawl fishery that operates in the California Current, only a relatively small percentage of the catch (approximately 5% by weight) is composed of noncommercial spp.
http://www.nwfsc.noaa.gov/research/divisions/fram/observer/sector_products.cfm.

FINAL SUITE OF INDICATORS

Recent analyses have shown that a single indicator is not sufficient to provide a complete picture of ecosystem state (Fulton et al. 2005); conversely, too many indicators can lead to too many conflicting signals that lead to indecision. Therefore, we ranked the evaluation scores of all 40 indicators for the ecological integrity goal and selected four of those ranked in the top quartile. Below we list the full suite of indicators chosen and discuss the final selection process.

From the 40 indicators ranked in the top quartile, we propose using these four as indicators in the CCLME during 2012:

- Zooplankton species biomass anomalies (specifically, *Northern copepod biomass anomaly*)
- Biodiversity (*Simpson's index of diversity*, with comparison to *Species richness*)
- *Mean trophic level*
- *Scavenger biomass*

The data sources we propose for these indicators, including extent of time-series and sampling frequency, are documented in Table EN2. The indicators we selected related to biodiversity and mean trophic level integrate a variety of time-series from among several components of the ecosystem (i.e., pelagic and demersal communities). The zooplankton indicator focuses on a single, critical component known to form the foundation of the ocean food web, linking oceanographic conditions and primary production to upper trophic levels. Scavenger biomass is another indicator of trophic structure which has been shown to respond to various fishing activities; it also serves to integrate data on crustacean populations (see the highly ranked, *crustacean survey trends* indicator), which can be highly responsive to top-down effects in the food web and predatory finfish populations.

We propose continuing the development of a fifth indicator in future assessments based on the strong scores of two phytoplankton-related indicators in our evaluation and the important role of phytoplankton in driving biomass production in the upwelling-driven CCLME. We will continue to accumulate, synthesize, and evaluate phytoplankton indicator data-series, including possibly several related to phenology, into 2013.

Habitat-based indicators, such as kelp forest coverage which ranked highly in this evaluation process, will likely form a separate component of the IEA in 2013.

Finally, several other indicators warrant more examination in the future, including *jellyfish* and *euphausid biomass*. Both showed promise by meeting most theoretical considerations in our evaluation, but lacked adequate historic data over a broad geographic scale. Notably, lower trophic level, high productivity functional groups like jellyfish and phytoplankton biomass showed relatively strong correlations with at least half of the ecosystem attributes in a food-web modeling exercise that evaluated the performance of candidate indicators of ecosystem structure and function (Samhouri et al. 2009). The emergence of several long-term datasets from multiple geographic regions along the coast may strengthen the scores of these indicators in 2013 and provide insight into where we might want to emphasize future data collection efforts.

Table EN2. Top-ranked indicators for Ecosystem Integrity.

Attribute / Guild	Indicator	Definition and source of data	Time series	Sampling frequency
Biodiversity	Simpson's index & Species Richness	Index of zooplankton community composition; measures dominance & number of species present in study area (Peterson et al., NOAA)	1996 – 2012	Biweekly
		Index of coastal pelagic species community composition, northern California Current (Brodeur et al., NOAA)	1998 – 2011	June, Sept; Annual
		Index of groundfish community composition (Keller et al. NWFSC)	2003 - 2011	Summers, Annual
		Index of seabird community composition; northern California Current (Zamon et al. NWFSC)	2004 - 2012	Summers, Annual
Trophic structure	Mean trophic level	Trophic structure of groundfish community (Keller et al. NWFSC)	2003 - 2011	Summers, Annual
		Trophic structure of coastal pelagic fish community (*currently in development*) (Brodeur et al., NOAA)	1998 – 2011	June, Sept; Annual
		Trophic structure of seabird community (*currently in development*)		
		Trophic structure of marine mammal community (*currently in development*)		
Trophic structure	Scavenger biomass	Relative biomass of scavengers, as defined by Brand et al. (2007), from fishery independent surveys (Keller et al. NWFSC)	2003 - 2011	Summers, Annual
Zooplankton community structure	Northern copepod anomaly	Monthly anomalies in the relative biomass of copepods with cold-water affinities off Newport, OR (Peterson et al., NOAA);	1996 – 2012	Biweekly

MAJOR FINDINGS

Indicators for Ecological Integrity are ecosystem and community level indices that were chosen to track two community level aspects of the CCLME: trinket structure (mean trophic level, scavenger biomass, and the northern copepod anomaly) and diversity (Simpson diversity, species richness). The extent to which the data for these indictors cover the California Current Large Marine Ecosystem (CCLME) varies among taxa. The groundfish data span the US west coast ($\sim$ 32-48 °N, $\sim$50-1200 m). Thus, conclusions for indicators based on the groundfish data set (MTL, scavenger biomass, species richness, species density and Simpson diversity) are applicable to the full extent of the CCLME. For coastal pelagic fishes, seabirds and copepods the data analyzed here are currently limited to the northern California current (NCC). See the Ecological Indicators: Data Sources and Methodology for a more complete discussion of the data sets.

Indicators of Ecological Integrity showed generally neutral or positive results, although there are some potentially important negative trends (summarized in Fig. EN.S., EN1). All indicators showed little in the way of long-term trends (quantified by comparing the mean of the last five years of the data set to the mean of the full time series). Given that most data sets are relatively short time series, this particular threshold is probably not highly informative since the last five years of many data sets contribute 50% or more of the data the time series.

DATA ANALYSIS AND PRESENTATION

The status of each indicator is evaluated against two criteria: recent short-term trend, and status relative to the long-term mean— reported as short-term status and long-term status, respectively. This approach holds for those indicators for which thresholds have not currently been set. For those indicators with established thresholds, those specific thresholds are used to evaluate the indicators.

Short-term trend. An indicator is considered to have changed in the short-term if the trend over the last five years of the time series showed an increase or decrease of more than 1.0 standard deviations (s.d.) of the mean of the entire time series.

Status relative to the long-term mean. An indicator is considered to be above or below historical norms if the mean of the last five years of the time series differs from the mean of the full time series by more than 1.0 s.d. of the full time series.

Most indicators (12 of 21) showed no short-term trend (trend over the last five years changed by less than 1.0 s.d. of the full time series) suggesting fairly stable status.

Six indicators increased in the short-term: groundfish Simpson diversity, groundfish species density, northern copepod anomaly for the winter, copepod species richness and Simpson diversity in the winter, and Simpson diversity for seabirds on the continental shelf in June. Additionally, some indicators like the northern copepod anomaly in the summer, while not triggering threshold values, suggest generally good ocean conditions.

Three indicators decreased in the short-term (trend over the last five years of the data decreased by more than 1.0 s.d. of the full time series). These include MTL of groundfishes, and seabird species richness and Simpson diversity in near shore waters for birds observed resting on-water. The causes of the decline in seabird diversity on the shelf are not known, but may indicate more recent changes in offshore conditions that have not been detected in other indicators. Seabird data are the most recent (June 2012), while many other indicator time series are current only to 2011 or the winter of 2011-12.

The decline in MTL represents approximately a 25% decrease in the primary production required to support the assemblage (Pauly and Christensen 1995, Essington et al. 2006) and may represent an important shift in the trophic structure of the groundfish community (but a temporary one within normal fluctuation, see

Branch et al. 2010). Previous work (Keller et al. 2012) suggests that proximal cause of the decrease in groundfish MTL was due to a decline in abundance of Pacific hake *Merluccius productus* and spiny dogfish *Squalus acanthias*. Hake in particular consume large amounts of forage fish and krill, and their lower abundance may mean an increase in food resources for other species that utilize these prey.

The decline in the biomass of Pacific hake and spiny dogfish is also likely the cause of the increase in Simpson diversity for groundfishes. Both fish are high biomass species. Because Simpson diversity is a measure of equitability of species abundance, a decline in the abundance of dominant species like hake and dogfish would lead to greater equitability (evenness) in the community.

Looking to the future

In the current IEA, the data for groundfishes span the US west coast. However, time series for the coastal pelagic fishes, seabirds and copepods were largely limited to the northern portion of the California current. Data exist for the central and southern California current for some of these taxa, but they were not available in the appropriate format in time to include in the present IEA. In the future, these additional data should be included so that the indicators span the CCLME and provide a more complete picture of the status of the CCLME.

Future work should also look to integrate or select data for those taxa with multiple data sources. In some cases, multiple data sets exist that were used to calculate the selected indicators. For example, three data sets (one with two time periods) were available for seabirds representing nearshore and shelf environments. Using multiple data sets produces a plethora of indicators, which can be difficult to evaluate. Combining multiple data sources to produce a single or at least fewer indicators for each taxon without losing important regional information (i.e., NCC vs. SCC) should be a goal of future work.

Indictors of trophic structure are currently limited to only several taxa – primarily groundfishes (and three crabs) and copepods. MTL time series for coastal pelagic fishes, seabirds and mammals will require some development. Many of the available data sets for these taxa are counts, while MTL is a biomass weighted average. Count data will, therefore, need to be converted to biomass using length-weight relationships or average adult biomass as appropriate for the taxon in question. Ultimately, efforts should focus on using these time series to produce a composite MTL or top predator biomass index that spans the geographic extent of the CCLME.
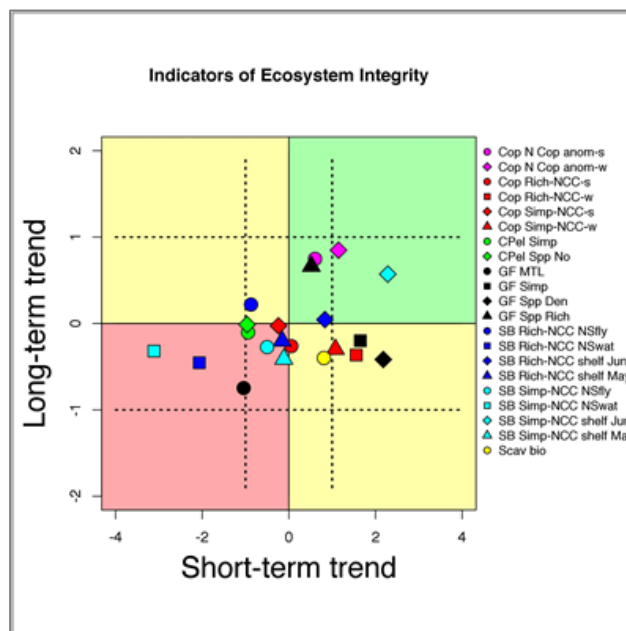
Figure EN.S.1. Short and long-term status of indicators of Ecological Integrity for the California Current Large Marine Ecosystem. Prior to plotting, time series were normalized to place them on the same scale. The short-term trend indicates whether the indicator increased or decreased over the last 5 years of the time series relative to the long-term mean. The long-term axis compares the mean of the last 5 years to the mean of the full time series. Changes or differences of more than 1.0 s.d. of the full time series (dotted lines) are considered to show an effect. Cop = copepod, Cpel = coastal pelagics, GF = groundfishes, SB = seabirds, anom = anomaly, Rich = species richness, Simp = Simpson diversity, Den = species density, Scav bio = scavenger biomass (GF and crabs), NS = nearshore (0-2 km), shelf=shelf waters (2070 km), s = summer,

MEAN TROPHIC LEVEL (GROUNDFISHES AND COASTAL PELAGIC FISHES)

Mean trophic level (MTL) is the biomass weighted average of the trophic levels of the species in a sample (Pauly et al. 1998). It is widely used as an indicator of change in trophic structure (Pauly and Watson 2005). Conceptually, a decrease in the abundance of higher trophic level predators (whether absolute or relative to lower trophic level taxa) influences the strength of trophic cascades and top-down forcing in the ecosystem. MTL comes in two forms (Branch et al. 2010). 'Catch MTL' is calculated from fisheries dependent data and reflects changing fishing practices and availability of target species. 'Ecosystem MTL' is calculated from fisheries independent data and represents changes in the ecosystem. MTL for groundfishes only is reported here. In the future, for an extended range of taxa (coastal pelagics, seabirds, mammals, highly migratory fishes etc) should be incorporated into the IEA either as individual indicators or as a composite MTL indicator.

MTL - GROUNDFISHES

Groundfish MTL was calculated from the West Coast Groundfish Bottom Trawl Survey, and therefore, produced an estimate of Ecosystem MTL for groundfishes.

MTL for groundfishes declined from 2003 until 2010 increasing marginally in 2011 (Fig. EN.S.2). The fluctuation over the entire time series was approximately 0.077 points from a high of 3.72 in 2004 to a low of 3.64 in 2010, which represents a ~25% decrease in the primary productivity required to support a given amount of catch (Pauly and Christensen 1995, Essington et al. 2006). While threshold values for MTL have not been set, future work could set thresholds based on changes in necessary primary production.

Over the last five years of the time series, groundfish MTL declined by more than 1.0 s.d. of the long-term mean. The mean of the last five years of the time series is within 1.0 s.d. of the full time series. However, given the short length of the time series (nine years), comparing the mean of the last five years with the mean of the full time series is of limited value, and the reader should focus on the short-term trend. Comparisons with other long-term data sets suggests that fluctuations in MTL are not uncommon (Branch et al. 2010).

INTERPRETATION OF TIME SERIES FIGURES

Time series figures. Most time series are plotted in a standard format. Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last five years of the time series, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the modeled trend over the last 5-years increased (↗), or decreased (↘) by more than 1.0 s.d., or was within one 1.0 s.d. (↔) of the long-term trend. The lower symbol indicates whether the mean of the last five years was greater than (+), less than (-), or within (·) one s.d. of the long-term mean.
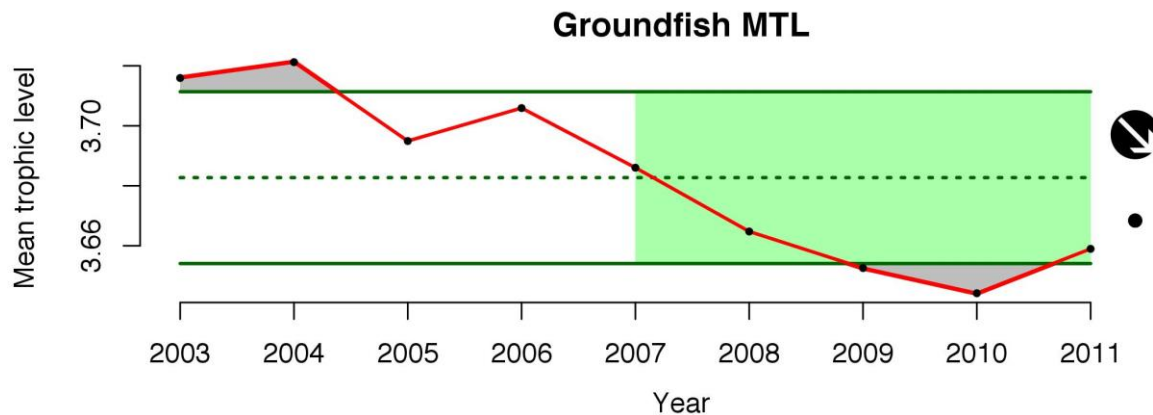
Figure EN.S.2. Area-weighted mean trophic level (MLT) for west coast groundfishes from 2003 – 2011. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness

MTL - COASTAL PELAGIC FISHES, SEABIRDS, MARINE MAMMALS

In development

SCAVENGER BIOMASS (GROUNDFISHES & CRABS)

Scavengers are generally defined as active foragers of carrion (Britton and Morton 1994). Changes in the biomass of scavengers are related to responses to fisheries discards and disturbance of bottom habitat due to trawling. The indicator presented here includes groundfishes and three species of crab quantified in the West Coast Groundfish Bottom Trawl Survey (see Data Sources and Methodology).

After an initially steep decline from 2003 to 2005, scavenger biomass has been fairly stable (Fig. EN.S.3). The trend over the last five years showed an increase of less than 1.0 s.d. of the full time series. The mean of the last five years was within 1.0 s.d. of the long-term mean. However, given the short length of the time series (nine years), comparing the mean of the last five years with the mean of the full time series is of limited value, and the reader should focus on the short-term trend.

Figure EN.S.3. Estimated biomass (CPUE) of groundfish and crab scavengers for the west coast shelf and slope from 2003-2011. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

SIMPSON DIVERSITY (GROUNDFISHES, COASTAL PELAGIC FISHES, SEABIRDS & COPEPODS)

Along with species richness, evenness is one of the two components of diversity. Simpson diversity (in the 1-λ form, a.k.a. Gini-Simpson index) is a measure of the equitability of species in a sample (Tuomisto 2012). When individuals are well distributed among species, Simpson diversity is high. For large samples, it approximates the probability of an interspecific encounter and is relevant to predator-prey relationships and food-web analyses. Diversity is related to community stability, production and ecosystem function.

SIMPSON DIVERSITY - GROUNDFISHES

Simpsons index (1-λ) for west coast groundfishes decreased between 2003 and 2008 (Fig. EN.S.4). Over the last five years (2007-2011) Simpson's index increased by more than one standard deviation (s.d.) of the complete time series to levels similar to 2003 and 2004. The mean of the last five years is within one s.d. of the long-term mean. However, given the short length of the time series (nine years), comparing the mean of the last five years with the mean of the full time series is of limited value, and the reader should focus on the short-term trend.
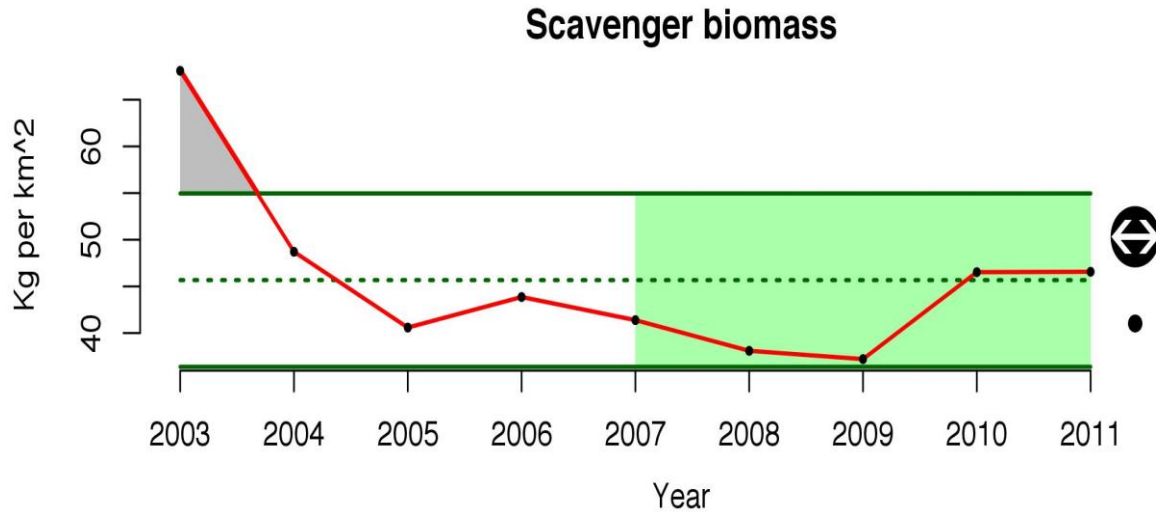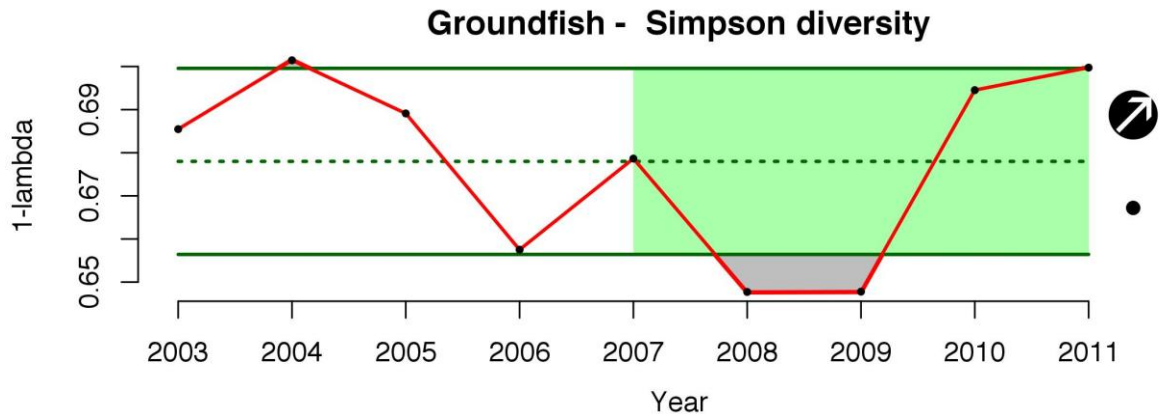
Figure EN.S.4. Simpson diversity (1-λ) for west coast groundfishes from 2003 to 2011. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

SIMPSON DIVERSITY - COASTAL PELAGIC SPECIES (FISH)

Simpson diversity for coastal pelagic species increased from the beginning of the time series in 1998 and reached a high in 2004 (Fig. EN.S.5). While it has declined since 2004 the trend from 2007 – 2011 (last five years of data) was stable with a minor decrease less than one s.d. of the full time series. The mean of the last five years of the time series was within one s.d. of the long-term mean.
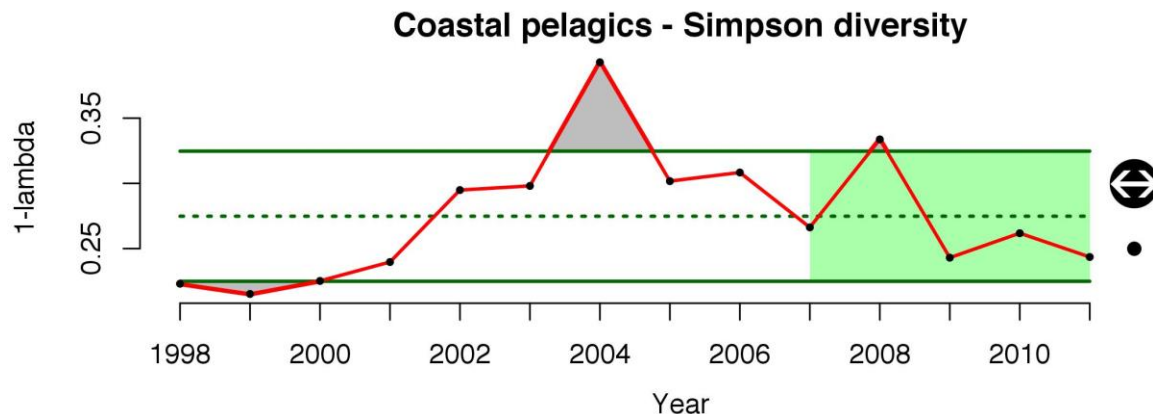
Figure EN.S.5. Simpson diversity (1-λ) for coastal pelagic fishes in the northern California current from 1998 to 2011.

SIMPSON DIVERSITY – SEABIRDS

Simpson diversity is presented for three surveys (one with two time periods) in the northern California current. Data for the southern California current exist but were not available at the time of publication in proper format for diversity analyses and should be added to future IEAs.

Trends in the nearshore and those on shelf/shelf break differ. For birds in the nearshore observed resting on the water (Fig. EN.S.6), Simpson diversity was fairly stable from 2004 to around 2008, after which it declined steadily to a low in 2012. The trend declined by more than 1.0 s.d. of the long-term mean over the last five years of the data set (2008-2012). While the mean of the last five years was within 1.0 s.d. of the mean of the full time series, the final two years were below the 1.0 s.d. line. Given the short duration of the time series, more emphasis should probably be place on the trend than on the mean of the last five years. While variable Simpson diversity for nearshore seabirds observed while flying did not show any trends over the last five years of the time series largely because of a low in 2008 (Fig. EN.S.7). Since 2009 there has been a steady decrease in Simpson diversity (over 2.0 s.d.) suggesting that the seabird community in the nearshore is coming to be dominated by fewer taxa. While the threshold (1.0 decline in the last five years) was not triggered in the current IEA year, the nearshore seabird community bears watching.
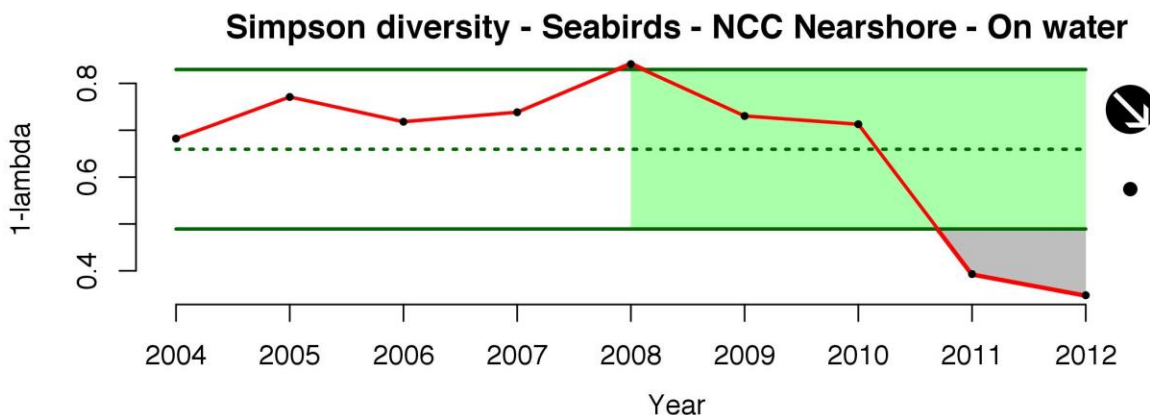
Figure EN.S.6. Simpson diversity for nearshore (within 2 km of shore) seabirds in the northern California current (NCC). Data are those birds observed and quantified while resting on water. Data courtesy of Jen Zamon (jen.zamon@noaa.gov).
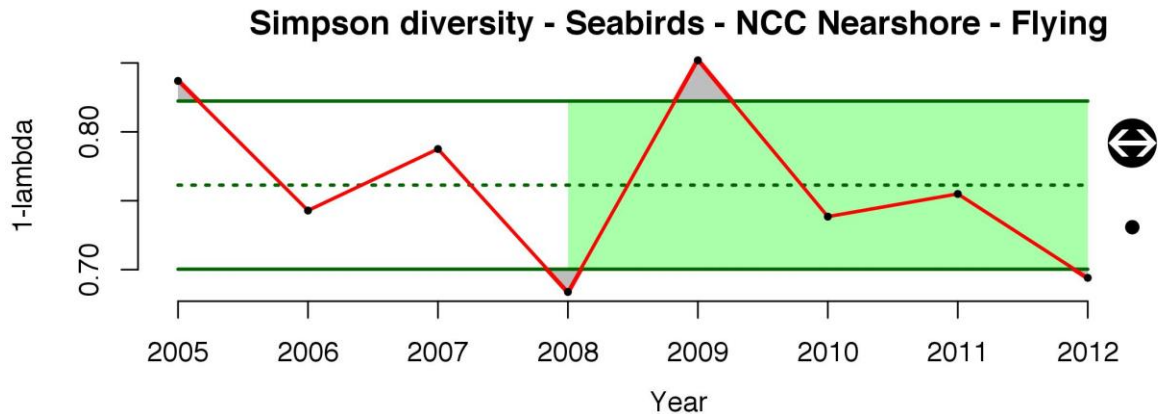
Figure EN.S.7. Simpson diversity for nearshore (within 2 km of shore) seabirds in the northern California current (NCC). Data are those birds observed and quantified while actively flying. Data courtesy of Jen Zamon (jen.zamon@noaa.gov).

In contrast to the nearshore, seabird diversity on the shelf (2-70 km offshore) increased in recent years. This increase was not seen in the data for May (Fig. EN.S.8), but in the June data (Fig. EN.S.9) Simpson diversity for seabirds increased of the last five years of the data series by more than 1.0 s.d. of the full data set. While the mean of the last five years of the data was within 1.0 s.d. of the mean of the full time series, Simpson diversity in June of 2011 and 2012 was above 1.0 s.d. of the mean of the full data set indicating high diversity in the most recent years.
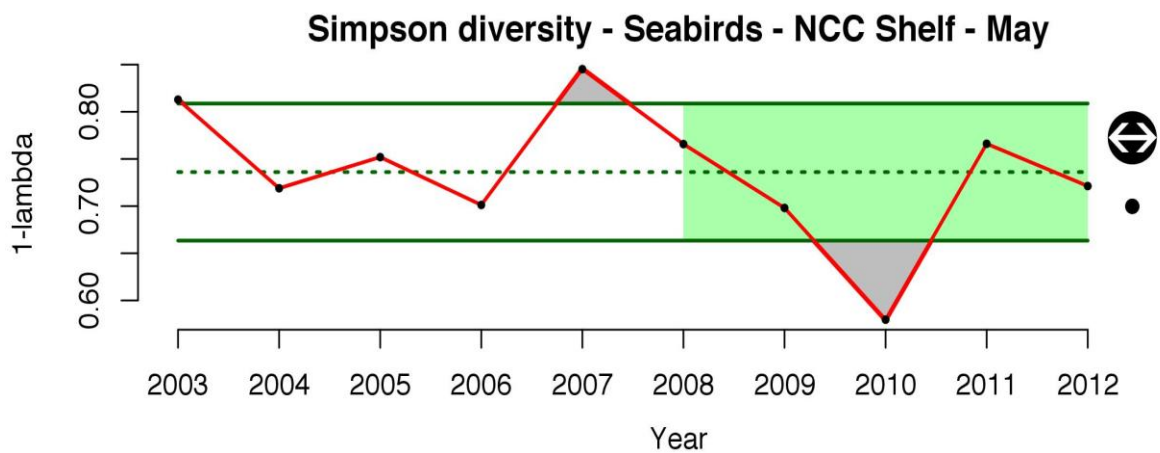
Figure EN.S.8. Simpson diversity in May for seabirds on the shelf and shelf break (2 – 70 km off shore) in the northern California current (NCC). Data courtesy of Jen Zamon (jen.zamon@noaa.gov).
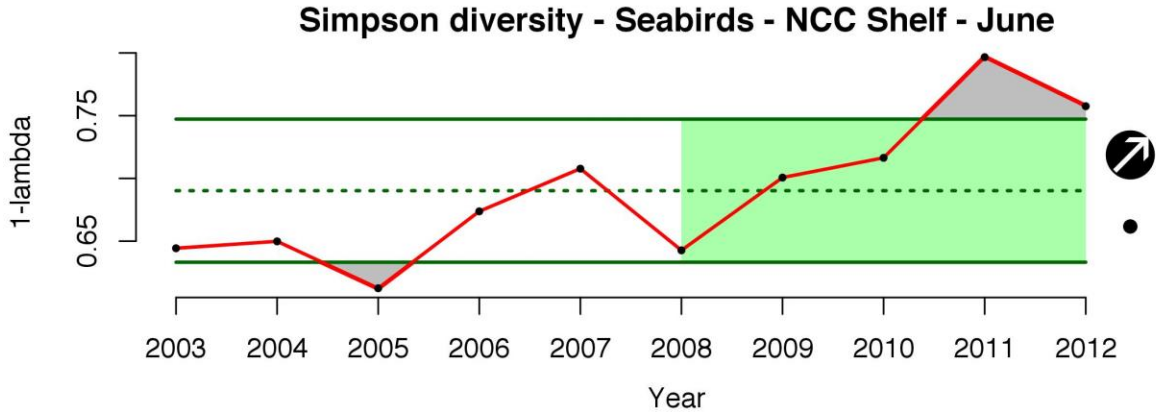
Figure EN.S.9. Simpson diversity in June for seabirds on the shelf and shelf break (2 – 70 km off shore) in the northern California current (NCC). Data courtesy of Jen Zamon (jen.zamon@noaa.gov).

SIMPSON DIVERSITY - COPEPODS

Simpson diversity for copepods was calculated by season using the same seasons as Peterson (2009) (Figs. EN.S.10-11). For all seasons Simpson diversity was variable through time. Simpson diversity for winter (Oct – April) assemblages showed a short-term increase (5-year trend trend showed an increase of greater than 1.0 s.d. of the full time series), but this increase is largely due to a rise from a historic low value in 2008. Visual inspection suggests that the trend has shifted to declining over the last two years. The mean of the last five years was within historical norms. Although the five-year trend showed an increase, closer inspection suggests that Simpson diversity is cycling within typical levels and has actually declined over the last two years. Simpson diversity for summer (May – Sept) assemblages showed no trend and the mean of the last five years was within 1.0 s.d. of the mean of the full time series.
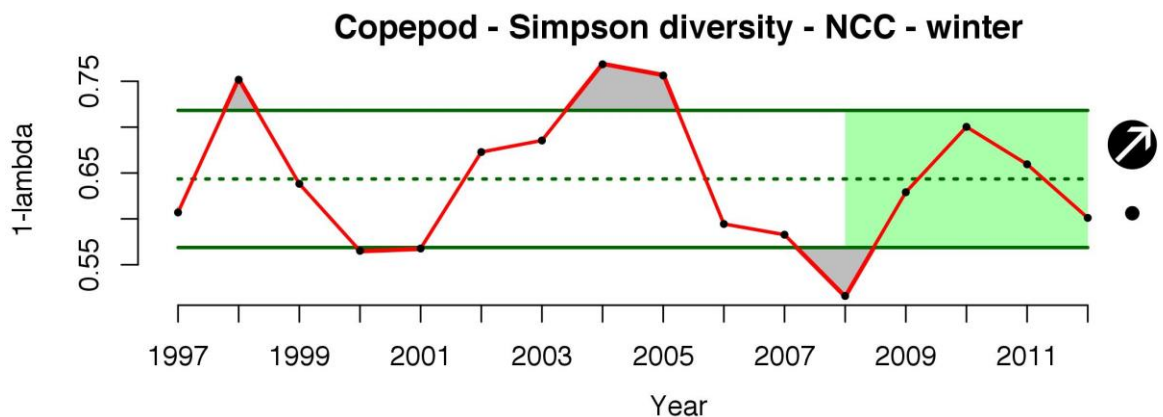
Figure EN.S.10. Time series of Simpson diversity (1-λ) from 1997 – 2012 for the winter (Oct–April) for west coast copepods in the northern California Current (NCC). Data courtesy of Bill Peterson (bill.peterson@noaa.gov).
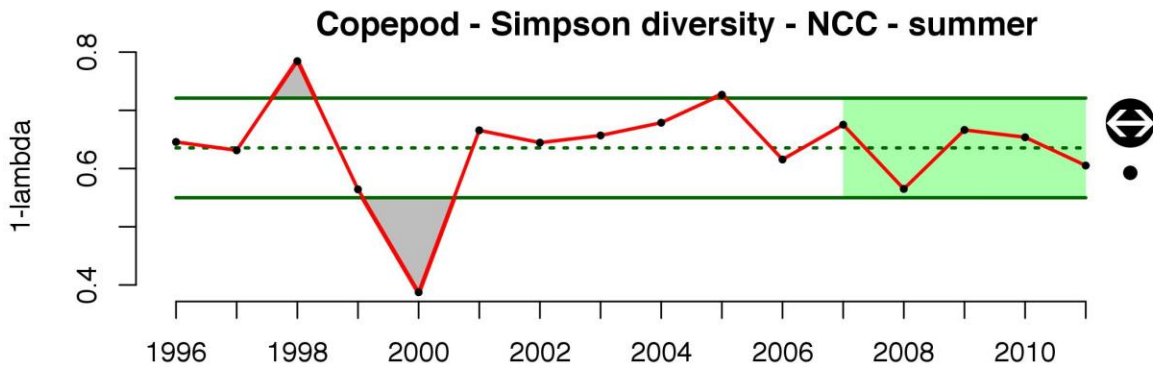
Figure EN.S.11. Time series of Simpson diversity (1-λ) from 1996 – 2011 for the summer (May – Sept) for west coast copepods in the northern California Current (NCC). Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

SPECIES RICHNESS & DENSITY (GROUNDFISHES, COASTAL PELAGIC FISHES, SEABIRDS & , COPEPODS)

Along with evenness, richness is one of the two components of diversity and is easily understood as the number of species in a community. Richness is important for many ecological models, and there is a substantial literature on the complex relationship between biodiversity and ecosystem function (Hooper et al. 2005, Stachowicz et al. 2007), with some consensus that community-level processes are more stable at higher richness.

Because sample effort, whether the number of individuals collected or area surveyed or both, has strong, non-linear effects on the number of species encountered, estimates of richness need to be scaled to a common effort level through rarefaction (Gotelli and Colwell 2001). The number of species in a community can then be presented in two forms: species richness and species density. Species richness in the rarefaction sense is the number of species observed for some number of individuals collected. Species density is the number of species per some unit area. Both are relevant to different questions and purposes. Since most theoretical models in ecology are based on *per capita* interactions, species richness is relevant to these models. At the same time, species density is important to conservation and applied purposes since it measures the number of species in a given area. Here, both species richness and species density are reported where possible based on the attributes of the particular data set. See Gotelli and Colwell (2001) further discussion of rarefaction and species richness and species density.

SPECIES RICHNESS & DENSITY - GROUNDFISHES

Species richness for west coast groundfishes increased steadily from 2003-2007 after which it has remained more or less stable (Fig. EN.S.12). The mean of the last five years was within 1.0 s.d. of the mean of the full time series and there was no short-term trend. Given the fairly recent implementation of the West Coast Groundfish Bottom Trawl Survey (< 10 years), the increase in richness in the early years may be related in part to better species identification over the development of the survey.
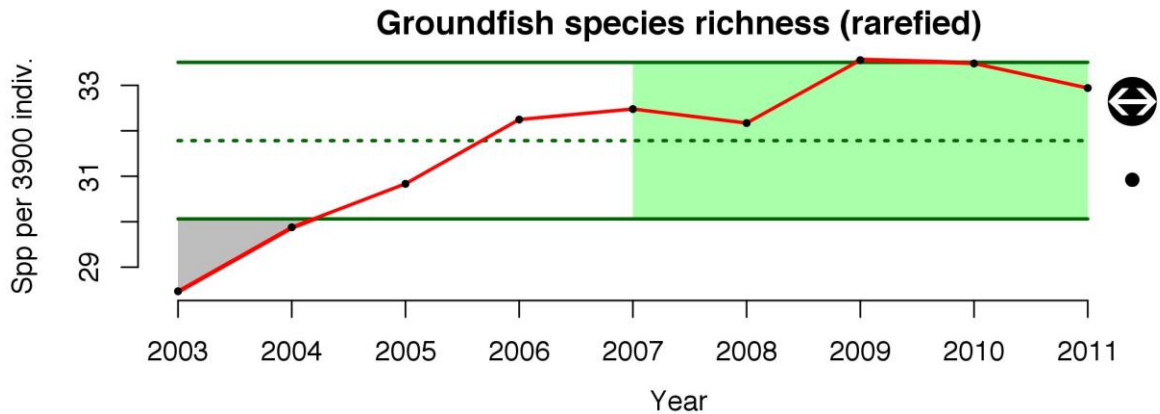
Figure EN.S.12. Species richness for west coast groundfishes from 2003 -2011. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Figure EN.S.13. Area-weighted mean number of groundfish species per 12 trawls for 2003-2011 from the from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Species density initially increased from 2003 – 2006 then decreased sharply in 2007-2008 (Fig EN.S.13). Over the last five years species density has increased by more than 1.0 s.d. of the full time series. Given the short length of the time series (nine years), comparing the mean of the last five years with the mean of the full time series is of limited value, and the reader should focus on the short-term trend.

The differences between species richness and species density trends seen in the first half of the groundfish data are likely driven by changing number of fishes in the trawl survey (Fig. EN.S.14-15). Both the mean number fishes per trawl and the median number of fishes per trawl declined from 2003 to 2007, after which they remained stable. From 2007 – 2011 species density increased. During this period the number of individuals per haul remained stable suggesting the increase was due to other processes.
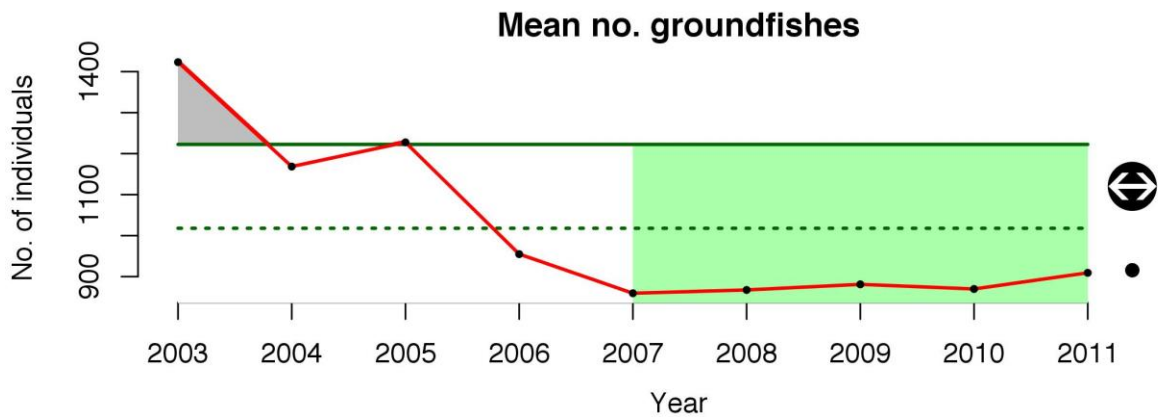
Figure EN.S.14. Mean number of groundfish individuals per trawl 2003-2011 from the from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

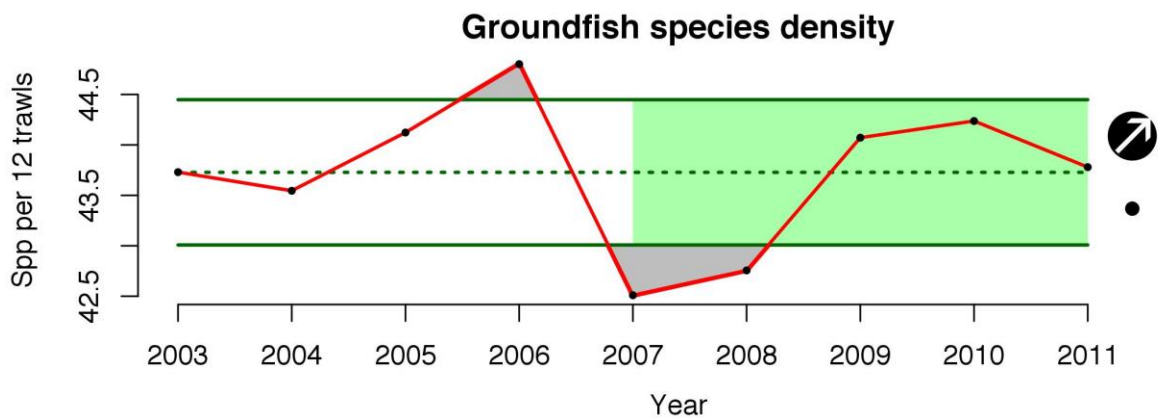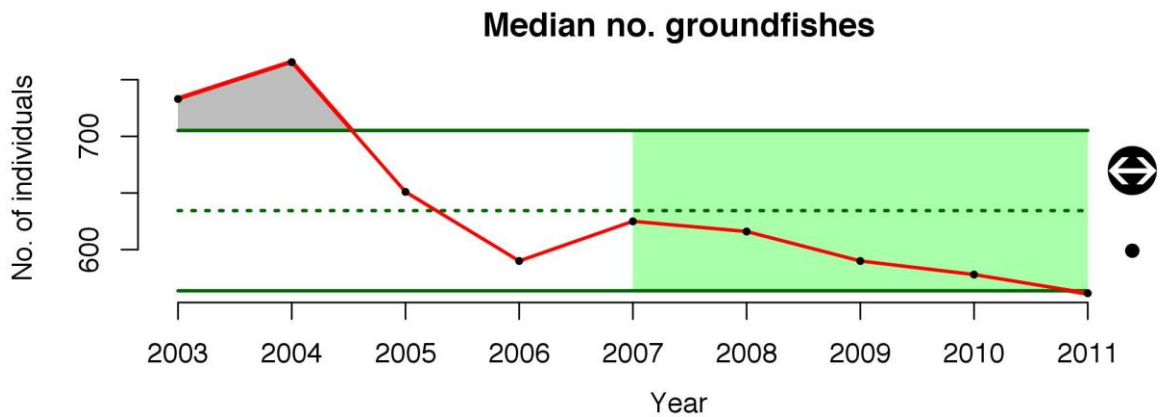**Figure EN.S.15.** Median number of groundfish individuals per trawl 2003-2011 from the from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Note that the trend in species richness seen here differs from that reported by Keller et al. (2012) who reported an initial decrease in the number of species per haul followed by an increase. The two trends differ because Keller et al. (2012) report raw species number per haul, while the data presented here were subject to rarefaction (Gotelli and Colwell 2001, Colwell et al. 2004). Additionally, the data in Keller et al. (2012) are better thought of as species density, since they are species per trawl for trawls with a relatively consistent area. The difference between Keller et al. (2012) and the richness values seen here is likely due to a decrease in the number of individuals per haul through time. Sampling effort (whether number of samples, area sampled or number of individuals collected affects estimates of richness with the number of species increasing with sampling effort non-linearly. Here data were subjected to sample-based rarefaction (since fish school individuals are not sampled at random) and rescaled to 3900 individuals (Colwell et al. 2004).

SPECIES NUMBER - COASTAL PELAGIC FISHES

Data for coastal pelagic fishes were not rarefied due to the data format. Mean number of species per sample for coastal pelagic fishes was variable through time with lows in 1999 and 2000 and 2010 and highs in 2003 and 2004 (Figure EN.S.16). Overall, however, current values are within the long-term norms (the mean of the last five years is within 1.0 s.d. of the long-term mean) with little trend over the last five years (change within 1.0 s.d. of the mean of the full time series.
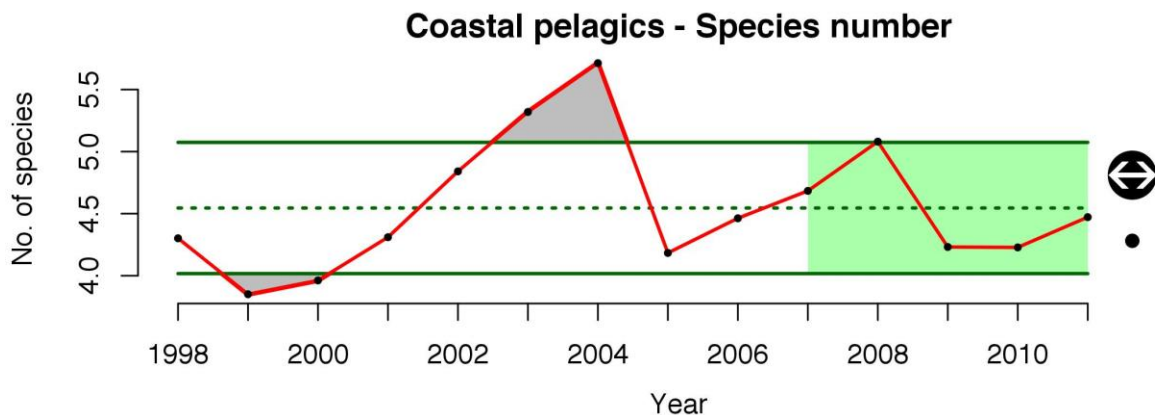
Figure EN.S.16. Mean number of species per sample for coastal pelagic fishes in the northern California current from 1998 to 2011.

TAXON RICHNESS—SEABIRDS

Richness for seabirds is presented as taxon richness since some taxa were pooled at levels above that of species. As seabird density increases it becomes increasingly hard to quantify and identify all individuals to the species level. For example all gulls were included in the taxon 'gulls' and all shearwaters in the taxon 'shearwaters'. Taxon richness is presented for three surveys in the northern California current (METHODS for data details). Data for the southern California current exist but were not available at the time of publication in proper format for diversity analyses and should be added to future IEAs. Data were subjected to individual-based rarefaction (Hurlbert 1971, Gotelli et al. 2009) to standardize for abundance.

Richness for seabirds in the nearshore has declined over the last five years for birds observed resting on the water (Fig. EN.S.17). While the mean over the last five years was within 1.0 s.d. of the mean of the full time series, the data for 2012 show the lowest levels of richness of the whole time series. For the birds observed flying in the nearshore (Fig. EN.S.18), richness declined substantially over the last three years of the data, but this decline was to levels only slightly lower than that seen earlier in the time series.
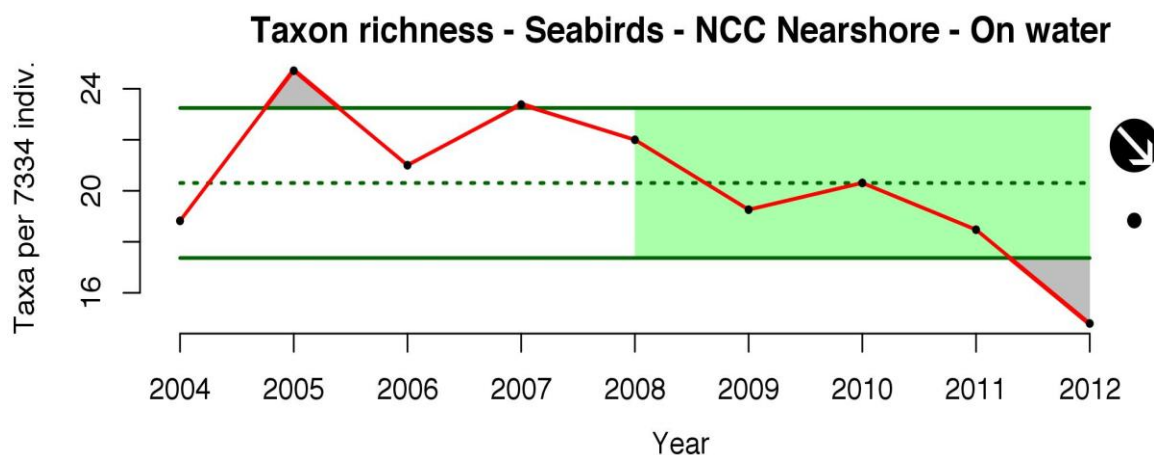
Figure EN.S.17. Taxon richness for seabirds observed while resting on water in the nearshore (< 2km from shore) for 2004-2012 for the northern California current (NCC). Data rarefied to 442 individuals (minimum seen in the time series) using individual-based rarefaction (Hurlbert 1971). Data courtesy of Jen Zamon (jen.zamon@noaa.gov).
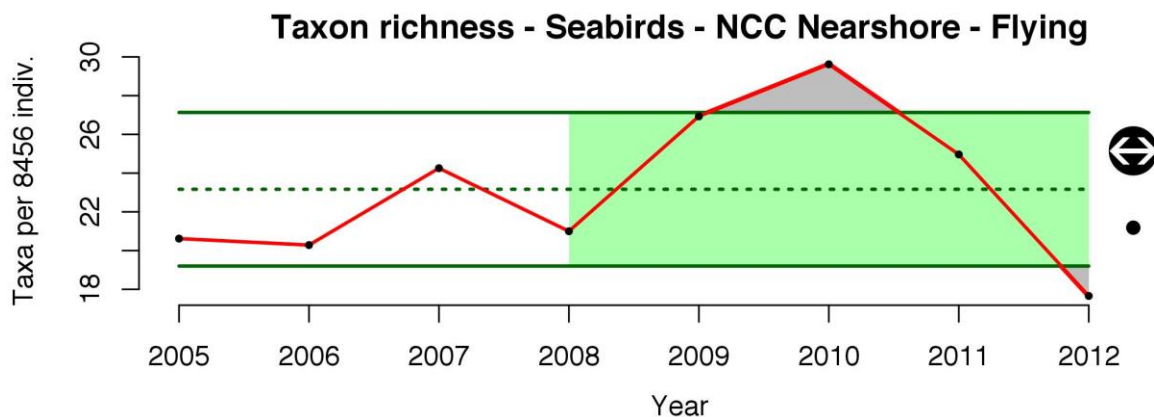
Figure EN.S.18. Taxon richness for seabirds observed while flying in the nearshore (< 2km from shore) for 2005-2012 for the northern California current (NCC). Data rarefied to 442 individuals (minimum seen in the time series) using individual-based rarefaction (Hurlbert 1971). Data courtesy of Jen Zamon (jen.zamon@noaa.gov).

Taxon richness for seabirds on the continental shelf showed no trends over the last five years of data, and the mean of the final five years was within 1.0 s.d. of the long-term mean in both May and June (Fig. EN.S.

19-20). For June data, the trend over the last five years appears to be increasing but the change was less than 1.0 s.d. of the full time series.
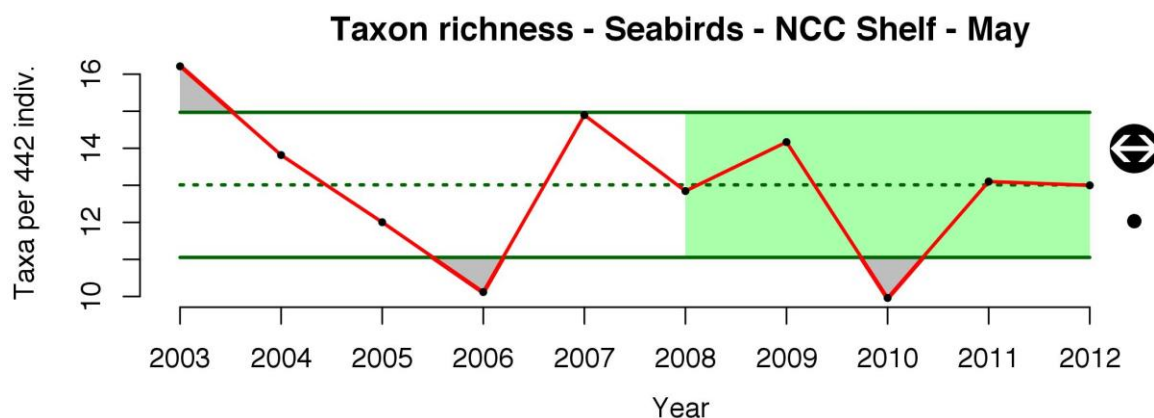
Figure EN.S.19. Taxon richness for seabirds May on the shelf and shelf break (2-70km from shore) for 2003-2012 for the northern California current (NCC). Data rarefied to 442 individuals (minimum seen in the time series) using individual-based rarefaction (Hurlbert 1971). Data courtesy of Jen Zamon (jen.zamon@noaa.gov).
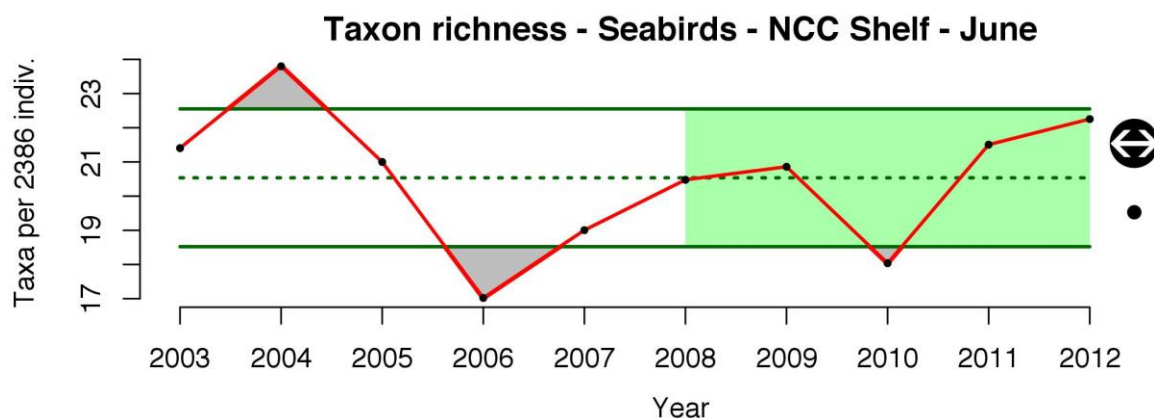
Figure EN.S.20. Taxon richness for seabirds May on the shelf and shelfbreak (2-70km from shore) for 2003-2012 for the northern California current (NCC). Data rarefied to 2386 individuals (minimum seen in the time series) using individual-based rarefaction (Hurlbert 1971). Data courtesy of Jen Zamon (jen.zamon@noaa.gov).

SPECIES RICHNESS - COPEPODS

Copepod species richness has been tied to food chain structure and survival of coho salmon *Oncorhynchus kisutch* in the California current (Peterson 2009). Low species richness is correlated with the southern transport of northern waters, high abundance of lipid-rich northern copepods and increased growth and survival of some species (Peterson 2009). Species density was not calculated for copepods.

Species richness for copepods (quantified as the number of species per sample of approximately 200-400 individuals) was highly variable over time (Figs. EN.S.21-22). Species richness for the winter assemblage showed an increasing trend in the short-term (an increase of more than 1.0 s.d. over the last five years) indicating worsening conditions in the short term. The mean of the last five years was within 1.0 s.d. of the long-term mean. While highly variable, species richness for the summer did not show any recent trends beyond typical cycling seen in the earlier parts of the time series.
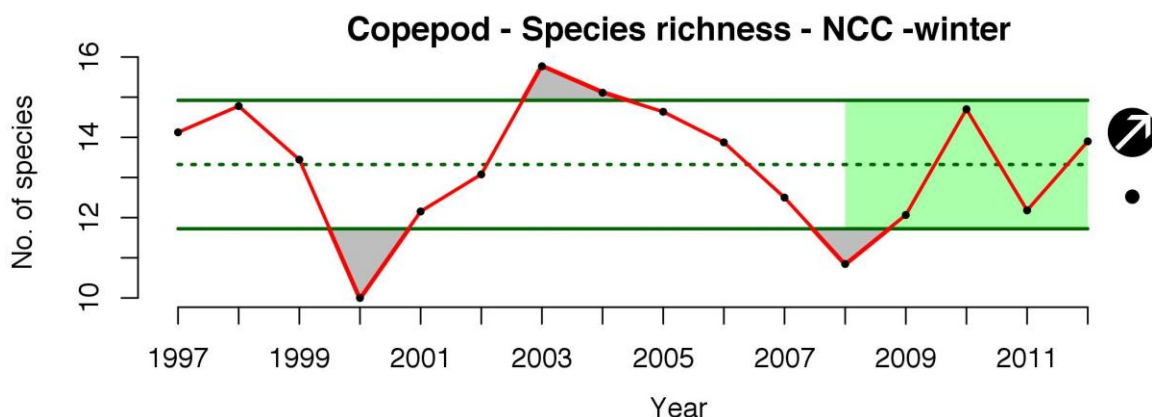
Figure EN.S.21. Copepod species richness for the winter in waters off Oregon in the northern California Current (NCC) from 1997-2012. Data courtesy of Bill Peterson (bill.peterson@noaa.gov).
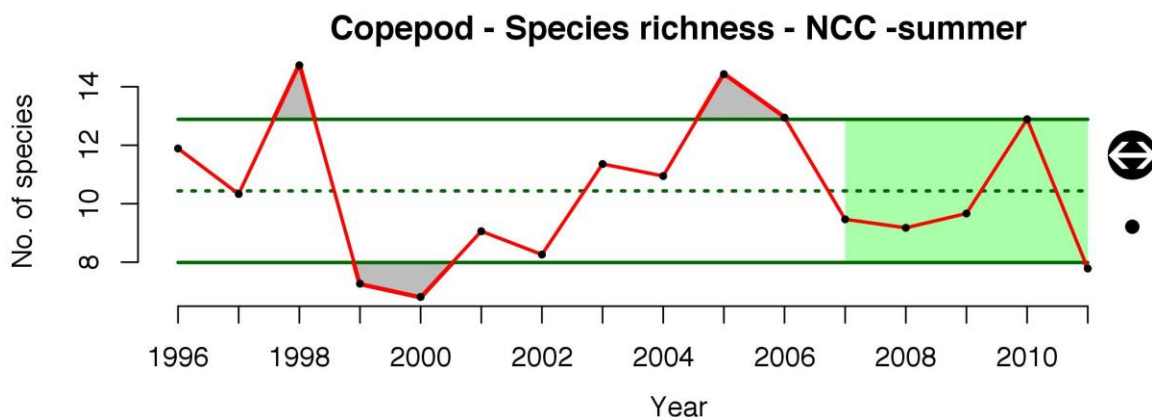
Figure EN.S.22. Copepod species richness for the summer in waters off Oregon in the northern California Current (NCC) from 1997-2012. Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

NORTHERN COPEPOD BIOMASS ANOMALY

The northern copepod biomass anomaly represents the ratio of northern and southern copepod species off of the Oregon coast. Two of the cold–water species, *Calanus marshallae* and *Pseudocalanus mimus*, are lipid–rich, and the index may represent the amount of lipid (wax–esters and fatty acids) available to pelagic fishes for whom these fatty compounds appear to be essential. Beamish and Mahnken (2001)

provide an example of this for coho salmon. See
http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/eb-copepod-anomalies.cfm for further detail.

The northern copepod anomaly has fluctuated between 1996 – 2012. In the last five years, the anomaly increased in the winter (Fig. EN.S.23), but there was no trend in the summer (Fig. EN.S.24). For both seasons, the mean of the last five years was within 1.0 s.d. of the long term mean of the full time series, although in the winter values for the last two years were above 1.0 s.d. of the long-term mean, as is the last data point for the summer time series. Threshold values for the anomaly have not been set. However, positive values in the summer period are correlated with stronger returns of fall and spring ocean-type Chinook to Bonneville dam, and values greater than 0.2 are associated with better survival of coho. Overall the high anomalies in recent years, especially for the summer data, suggest that ocean conditions are in a generally good state.

See http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/eb-copepod-anomalies.cfm for further detail.
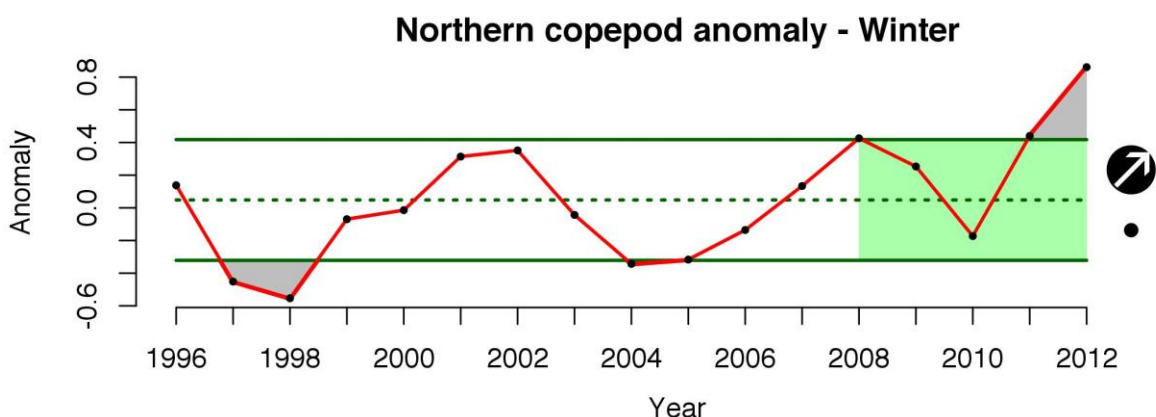
Figure EN.S.23. Northern copepod biomass anomaly for 1996-2012 in the waters off of Oregon during the winter (Oct-April). Data courtesy of Bill Peterson.
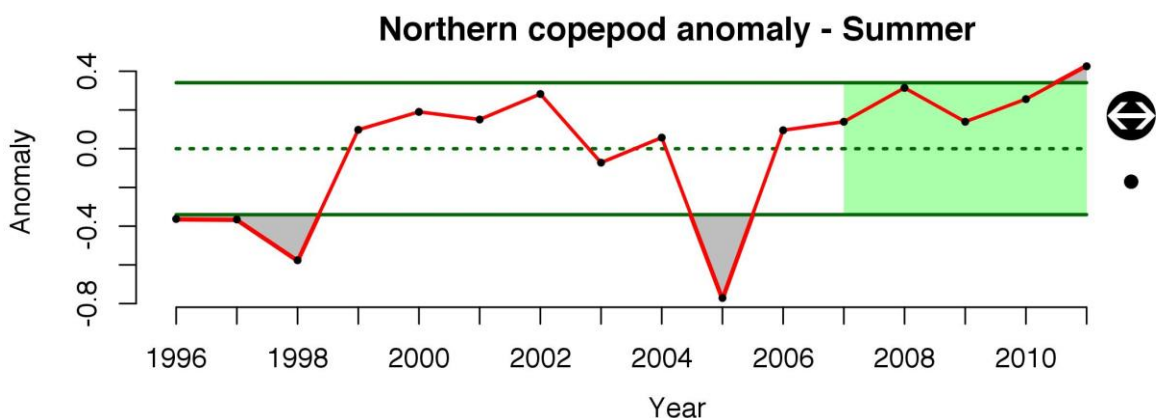
Figure EN.S.24. Northern copepod biomass anomaly for 1996-2012 in the waters off of Oregon during the summer (May - Sept). Data courtesy of Bill Peterson.

DATA SOURCES AND METHODOLOGY

GROUNDFISHES

Data for the groundfish time series come from the Northwest Fisheries Science Center's annual West Coast Bottom Trawl Survey (WCBTS, data courtesy of Beth Horness, beth.horness@noaa.gov)(Keller et al. 2008). The survey is a depth stratified, random sample that spans approximately 32 - 48.5^o N and 55-1200 m depth for 2003-2011. Data were limited to those hauls deemed acceptable for stock assessment. Hauls from areas subsequently closed to sampling were not included in analyses. The data include 5743 trawls/hauls from 2003 - 2011 and 313 taxa identified to species. Of these two pairs of rockfishes were combined because of difficulty in discriminating between each species pair in the field. Sunset rockfish *Sebastes crocotulus* and vermilion rockfish *S. miniatus* were combined into one taxa. Blackspotted rockfish S. *melanostictus* and rougheye rockfish *S. aleutianus* were also combined into a single taxa. Both combined taxa were included in species level analyses.

AREA-WEIGHTED MEANS (GROUNDFISHES)

Area-weighted means were calculated for mean trophic level, scavenger biomass, Simpson diversity, and species richness because some areas of the shelf and slope are more heavily sampled than others and because the total bottom area of the shelf and slope for any given depth range varies with latitude (Table EN.S.1).

Data (for both groundfishes and bottom area) were binned into five depth zones (<200, 201-600, 600-1200 m depth) and four latitude regions (south of Point Conception [32 - 34.5^o N], Point Conception to Cape Mendocino 40.4^o N], Cape Mendocino to Cape Blanco [42.5^o N], and Cape Blanco to Cape Flattery (actual 48.38 but here to 48.4511^o N—the extent of the groundfish data) based on previous analyses on groundfish assemblage structure (Tolimieri and Levin 2006, Tolimieri 2007). The areal extent of each depth x region bin was calculated from the U.S. Coastal Relief Model (http://www.ngdc.noaa.gov/mgg/coastal/crm.html). The native coordinate system of these bathymetry data does not conserve area throughout the study region (e.g., a 1 X 1 degree area in the south is larger than a 1 X 1 degree area to the north). To correct this problem, we created a regular 1/10 degree grid over the study area and then re-projected this grid to a Cylindrical Equal-Area projection (units = meters, projection type = 3, longitude of the centre of projection = -122 0' 0.00", latitude of the centre of projection = 56 30' 0.00", Azimuth = 120.95, and Scale factor = 1). The new data layer had the correct area for each 1/10 degree latitude/longitude grid cell. The total area of a given depth x region bin was calculated by summing the area of the relevant grid cells. Each depth x region bin was then assigned a weight equal to its proportion of the total area of all depth x region bins. These weights were then used to calculate the area-weighted mean for each groundfish-based indicator of ecological integrity.

Table EN.S.1. Depth and latitude bins uses in the area-weighted analyses showing total area of the bins, corresponding weights and total number of trawls from 2003 – 2011. See text for depth and latitude borders.

Depth zone	Latitude zone	Total area (km^2)	Weight	Trawls
Shelf	Flattery	36,394	0.231	1289
Shallow slope	Flattery	11,020	0.070	707
Deep slope	Flattery	10,916	0.069	439
Shelf	Blanco	5,407	0.034	232
Shallow slope	Blanco	2,182	0.014	180
Deep slope	Blanco	5,258	0.033	220
Shelf	Mendocino	16,689	0.106	672
Shallow slope	Mendocino	8,326	0.053	511
Deep slope	Mendocino	12,518	0.079	420
Shelf	Conception	10,176	0.064	314
Shallow slope	Conception	11,702	0.074	431
Deep slope	Conception	27,243	0.173	270

INDICATORS

Mean trophic level (MTL, Pauly and Watson 2005, Branch et al. 2010) was calculated as the biomass-weighted mean trophic level for each haul, which was then used to calculate an area-weighted mean for the west coast shelf and slope (see Area-weighted means, below). Information on trophic level was taken from Fishbase.org. Taxa included in the analyses were all fishes identified to the species level. Data were CPUE biomass (kg per km^2) by species per haul.

Previous analyses of MTL (Pauly et al. 2001, Essington et al. 2006, Branch et al. 2010) have generally not corrected for survey area. In part this is because many workers have focused on catch-MTL, which is derived from fisheries catch data. The data used here are from a fishery-independent trawl survey, and therefore, represent ecosystem-MTL. To correctly evaluate the change in the trophic structure of the groundfish assemblage it is important to correct the data for survey area since the total area of various depth x latitude bins is not constant.

Area-adjust MTL for groundfishes is presented in the results section. For comparison, the raw MTL trend is shown below (Fig. EN.S.25). While the over all trend is similar (a decline from 2003), there are important differences. Adjusting for area. Most importantly the absolute level of decline is quite different: 0.077 when adjusting for area versus 0.19 not. A decrease in MTL of ~0.15 represents a decrease of 50% in the primary production required to support the assemblage. Therefore, failing to account for sample area, overestimates the change in the trophic structure and energy requirements for the assemblage in question.
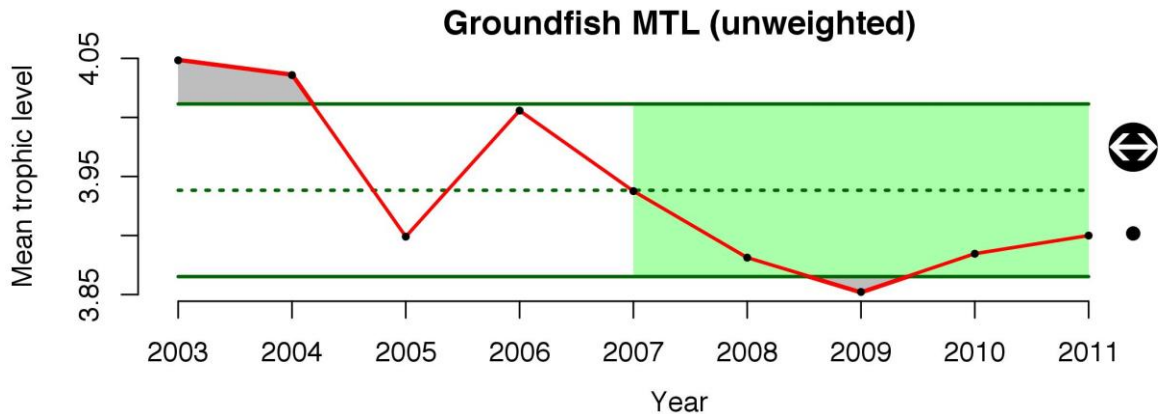
Figure EN.S.25. Mean trophic level for west coast groundfishes from 2003 – 2011. MTL was calculated for survey data without adjusting for sampling effort in different depth x laitutde strata. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Scavenger biomass was calculated from the West Coast Bottom Trawl Survey (WCBTS), which provides quantitative biomass data for groundfishes, as well as for several crab species for 2003-2011. We followed Brand et al. (2007) and Horne et al. (2010) in defining large crabs, large demersal sharks and grenadiers as scavengers (Table EN.S.2). Further detail was taken from Yeh and Drazen (2011) who used baited-cameras to evaluate scavenger ecology on the California slope, and from Buckley et al. (1999) who examine food habits of several groundfishes. Scavengers are generally defined as active foragers of carrion (Britton and Morton 1994). Many of the species on the list are predators that responded strongly to baited cameras (grenadiers) or had large amounts of fisheries offal in their diet (thornyheads and sablefish). While carrion may not normally make up a substantial portion of the diets of these animals in the absence of anthropogenic influences, part of the objective of monitoring scavenger biomass is to track the effects of fisheries on the ecosystem. Therefore, it is relevant to include taxa that respond strongly to these activities. Scavenger biomass was calculated for each haul by summing the CPUE biomass of all taxa. Biomass (CPUE) per haul was then used to calculate the area-weighted mean CPUE per trawl (kg per km^2, see Area-weighted means, below). Data were biomass by species per km^2 (CPUE, kg/km^2).

Table EN.S.2. Groundfish and decapod taxa included in the quantification of scavenger biomass 2003-2011. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Species	Family	Order	Class	Total catch (kg)
Albatrossia pectoralis	Macrouridae	Gadiiformes	Actinopterygii	17,421.2
Coelorinchus scaphopsis	Macrouridae	Gadiiformes	Actinopterygii	0.4
Coryphaenoides acrolepis	Macrouridae	Gadiiformes	Actinopterygii	30,221.2
Coryphaenoides cinereus	Macrouridae	Gadiiformes	Actinopterygii	40.0
Coryphaenoides filifer	Macrouridae	Gadiiformes	Actinopterygii	0.5
Macrouridae	Macrouridae	Gadiiformes	Actinopterygii	0.0
Malacocephalus laevis	Macrouridae	Gadiiformes	Actinopterygii	0.2
Nezumia liolepis	Macrouridae	Gadiiformes	Actinopterygii	132.6
Nezumia stelgidolepis	Macrouridae	Gadiiformes	Actinopterygii	257.4
Antimora microlepis	Moridae	Gadiiformes	Actinopterygii	2,793.2

Species	Family	Order	Class	Total catch (kg)
Anoplopoma fimbria	Anoplopomatidae	Scorpaeniformes	Actinopterygii	81,309.6
Bolinia euryptera	Cottidae	Scorpaeniformes	Actinopterygii	4.6
Chitonotus pugetensis	Cottidae	Scorpaeniformes	Actinopterygii	3.1
Clinocottus acuticeps	Cottidae	Scorpaeniformes	Actinopterygii	1.5
Enophrys bison	Cottidae	Scorpaeniformes	Actinopterygii	2.9
Enophrys taurina	Cottidae	Scorpaeniformes	Actinopterygii	9.3
Gymnocanthus tricuspis	Cottidae	Scorpaeniformes	Actinopterygii	2.4
Hemilepidotus hemilepidotus	Cottidae	Scorpaeniformes	Actinopterygii	3.0
Hemilepidotus spinosus	Cottidae	Scorpaeniformes	Actinopterygii	3.5
Icelinus borealis	Cottidae	Scorpaeniformes	Actinopterygii	0.0
Icelinus burchami	Cottidae	Scorpaeniformes	Actinopterygii	1.7
Icelinus filamentosus	Cottidae	Scorpaeniformes	Actinopterygii	480.6
Icelinus fimbriatus	Cottidae	Scorpaeniformes	Actinopterygii	4.2
Icelinus tenuis	Cottidae	Scorpaeniformes	Actinopterygii	0.6
Jordania zonope	Cottidae	Scorpaeniformes	Actinopterygii	1.6
Leptocottus armatus	Cottidae	Scorpaeniformes	Actinopterygii	67.5
Paricelinus hopliticus	Cottidae	Scorpaeniformes	Actinopterygii	0.0
Radulinus asprellus	Cottidae	Scorpaeniformes	Actinopterygii	2.8
Radulinus taylori	Cottidae	Scorpaeniformes	Actinopterygii	0.1
Scorpaenichthys marmoratus	Cottidae	Scorpaeniformes	Actinopterygii	5.0
Triglops macellus	Cottidae	Scorpaeniformes	Actinopterygii	0.2
Sebastolobus alascanus	Scorpaenidae	Scorpaeniformes	Actinopterygii	35,692.5
Sebastolobus altivelis	Scorpaenidae	Scorpaeniformes	Actinopterygii	101,664.0
Sebastolobus sp.	Scorpaenidae	Scorpaeniformes	Actinopterygii	0.0
Hexanchus griseus	Hexanchidae	Hexanchiformes	Chondrichthyes	102.5
Eptatretus deani	Myxinidae	Myxiniformes	Myxini	219.8
Eptatretus sp.	Myxinidae	Myxiniformes	Myxini	2.0
Eptatretus stouti	Myxinidae	Myxiniformes	Myxini	89.7
Cancer magister	Canceridae	Decapoda	Malacostraca	42,227.1
Chionoecetes bairdi	Oregoniidae	Decapoda	Malacostraca	14.6
Chionoecetes tanneri	Oregoniidae	Decapoda	Malacostraca	27,762.5

Simpson Diversity (1-λ, Gini-Simpson index) was calculated (using the vegan package in R 2.15(R Development Core Team 2012)) for each haul and then used to calculate an area-weighted mean for the west coast shelf and slope (see Area-weighted means, below). Taxa included in the analyses were all fishes identified to the species level (319 species). Data were number of individuals by species per haul.

Species Richness and Species Density were calculated for each depth x latitude bin (see Area-weighted means, below) and then used to derive the area-weighted mean for the combined west coast shelf and slope. Because the number of species per sample will increase in relation to sampling effort non-linearly (either area or number of individuals), the groundfish data required rarefaction to standardize annual estimates of species richness and species density (Gotelli and Colwell 2001). Individual based rarefaction assumes that individuals are randomly distributed in space or time (Gotelli and Colwell 2001), and is, therefore, not the

best approach for fishes since many species school. Individual based rarefaction will tend to overestimate species richness when individuals are patchily distributed (Colwell et al. 2004). Instead, sample-based rarefaction was used to calculate species density curves by pooling samples (trawls) in depth x latitude bins. Rarefraction was conducted using the 'specaccum' function in the 'vegan' package for R 2.15 (Mao Tau, Colwell et al. 2004, R Development Core Team 2012).

Sample-based rarefaction curves initially produce estimates of species density (species per area) and not species richness (species *per capita*), and data need to be re-scaled to the number of species per some number of individuals based on the mean number of individuals per trawl (Gotelli and Colwell 2001). Since the purpose was not to estimate mechanism, a high-order polynomial was chosen to maximize fit (minimum $r^2 = 0.9988$ for all regressions) and to achieve the best fits at the lower end of the data range where more mechanistic models overestimate the number of species. Rarefraction by samples produced an estimated number of species per cumulative number of samples from one to the total number of samples for each depth x latitude bin. For each depth x latitude bin, the mean number of individuals per haul was calculated and multiplied by the number of samples (1 to total) to give the cumulative expected number of individuals per total samples. This number of individuals per total samples was then used in the regression analysis to predict richness. Rarefied data were rescaled to the number of species per 3900 individuals. The reference value of 3900 individuals was chosen based on two criteria. First, it was larger than the smallest mean number of individuals per sample for all depth x latitude bins so that all predicted values were from within the range of the data. Second if was just smaller than the number of individuals (3991) from the depth x latitude bin with he lowest total number of individuals per 12 samples (the lowest number of samples from a depth x latitude bin by year). Species richness for a given year was then calculated as the area-weighted mean richness for that year.

For background the raw number of species per trawl is presented here (Figure EN.S.26) and should be considered analogous to species density since the data are species per area (trawls of more or less consistent swept area). Raw species density declined around 2007-2008 but then subsequently increased.
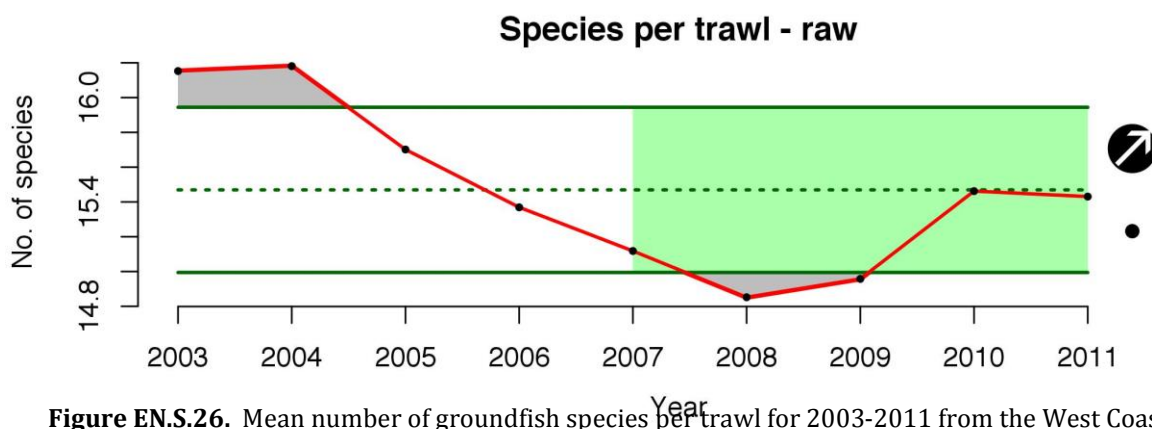
Figure EN.S.26. Mean number of groundfish species per trawl for 2003-2011 from the West Coast Groundfish Bottom Trawl Survey. Species number values were not subjected to rarefaction. Data courtesy of Beth Horness (Beth.Horness@noaa.gov).

The initial decrease in species per trawl is probably related to a decline in the number of individuals per trawl (see Species Richness & Species Density - Groundfishes). The increase in species richness later in the time series may be attributable to better species identification. The number of species identified in any given year has increased over the time series by about 25-30 species from 2003 to 2011 (Fig. EN.S.27a). The total number of species recorded by the trawl survey has steadily increased as expected by species-area relationships (Fig. EN.S.27b).
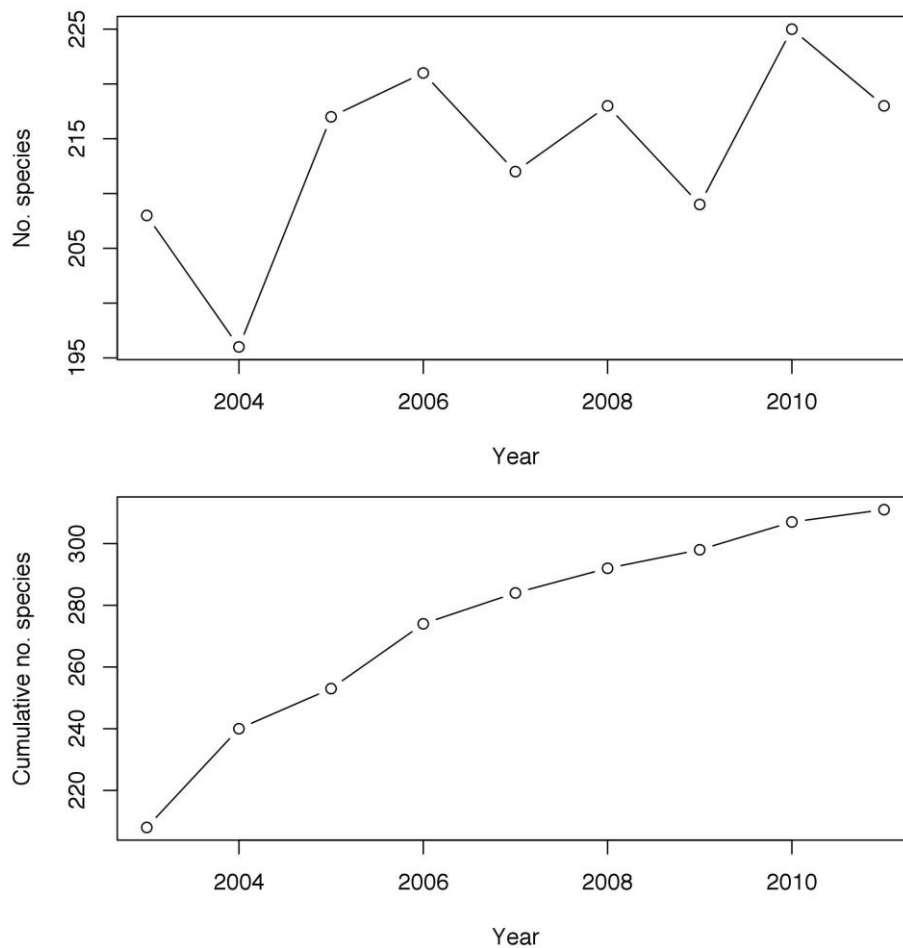
Figure EN.S.27. (A) Number of species identified in any given year by the trawl survey, (B) cumulative number of species identified by the trawl survey.

COASTAL PELAGIC FISHES

Data courtesy of Rick Brodeur (Richard.brodeur@noaa.gov). See the 'Data Sources and Methodology' for the Coastal Pelagic Fishes section for details on the data collection and processing.

Mean Trophic Level for coastal pelagic fishes (MTL, Pauly and Watson 2005, Branch et al. 2010) was calculated as the biomass-weighted mean trophic level for each haul and then averaged for each year. Information on trophic level was taken from Fishbase.org and updated based on current research (R. Brodeur, unpublished data). Taxa included in the analyses were all fishes identified to the species level. Counts of individuals per haul were transformed to biomass per haul using length-weight relationships and size class data from the survey..

Simpson Diversity (1-λ, Gini-Simpson index) was calculated for each sample and then averaged for each year. Samples from June and September were pooled to create a single annual value.

Species richness data for coastal pelagic fishes were not subject to rarefaction as they were not count data), and are raw estimates of species per sample. The number of species was calculated for each sample and then averaged for each year. Samples from June and September were pooled to create a single annual value.

SEABIRDS

Data are courtesy of Jen Zamon (jen.zamon@noaa.gov). For specifics on seabird data sets and collection see 'Data Sources and Methodology' in the Seabirds section.

Data analyzed here were total counts for the BPA and Lighthouse (On-water and Flying) data sets. The Lighthouse data are for the nearshore (0-2 km from shore). The BPA data set is for the shelf and shelfbreak (2-70 km from shore). Both are for the northern California current. The data are total counts by species or taxa for the sampling period (month or year). As seabird density increases, it become increasing difficult to quantify all individuals to species and some taxa are pooled into broader groups during the survey. Therefore, for the analyses some species were collapsed to higher-level taxa for analysis. For the BPA data all gulls, shearwaters and phalarope species were pooled into broader taxa (i.e., gulls, shearwaters and phalaropes) for analysis. For the Lighthouse data seabirds were pooled into cormorants, gulls, phalaropes, scaups, scoters, geese, ducks, loons, and shorebirds. Individual species not belonging to one of these groups remained categorized as individual species.

Simpson Diversity (1-λ, Gini-Simpson index) was calculated for each time period based on total counts within that sampling period.

Species richness was calculated using individual-based rarefaction on the total counts of individuals within a sampling period using the 'rarefy' function in the 'vegan' package for R. (Hurlbert 1971, R Development Core Team 2012).

COPEPODS

Data courtesy of Bill Peterson (bill.peterson@noaa.gov). See Peterson (2009) for details on the data collection and processing.

Note that the data are for the 'Newport Line' near Newport OR and do not span the full coast. Future IEA efforts should work to incorporate available data sets to produce better coastwide estimates zooplankton dynamics. Work has shown that copepod diversity calculated from this data source is a good predictor or system characteristics and correlates with population dynamics of some salmon species (Peterson 2009).

Simpson Diversity (1-λ, Gini-Simpson index) was calculated for each sample/tow then averaged for each year by season following XXX: winter (Oct - April) and summer (May – Sept). Data were number of individuals by taxa per m^3. Winter means included data from the previous calendar year. That is, winter 2000 was the average of data from Oct – Dec 1999 and Jan – April 2000.

Species richness estimates of species per sample were not subject to rarefaction as in the case of groundfish. Enumeration of zooplankton data uses subsamples of a generally consistent number of individuals (200-400 individuals per sample for copepods, Peterson 2009), and therefore, does not require rarefaction to account for differences in sampling effort.

NORTHERN COPEPOD BIOMASS ANOMALY

Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

See http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/eb-copepod-anomalies.cfm for a discussion of the mechanisms behind the northern copepod biomass anomaly and for methodology in calculating the index. Seasonal estimates of the anomaly were calculated winter (Oct - April) and summer (May – Sept). Winter means included data from the previous calendar year. That is, winter 2000 was the average of data from Oct – Dec 1999 and Jan – April 2000.

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